AD-A254 532

AD

(2)

DIESEL INJECTOR FOULING BENCH TEST METHODOLOGY

INTERIM REPORT
BFLRF No. 267

DTIC
S ELECTE AUG 2 5 1992 D
C

By

L.L. Stavinoha
D.M. Yost
S.J. Lestz

Belvoir Fuels and Lubricants Research Facility (SwRI)
Southwest Research Institute
San Antonio, Texas

Under Contract to

U.S. Army Belvoir Research, Development
and Engineering Center
Logistics Equipment Directorate
Fort Belvoir, Virginia

Contract No. DAAK70-87-C-0043

Approved for public release; distribution unlimited

June 1992

387339 103 Pg

92-23555

92 8 24 059

Unclassified
SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

1a. REPORT SECURITY CLASSIFICATION Unclassified	1b. RESTRICTIVE MARKINGS None
2a. SECURITY CLASSIFICATION AUTHORITY N/A	3. DISTRIBUTION/AVAILABILITY OF REPORT Approved for Public Release; Distribution Unlimited
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE N/A	
4. PERFORMING ORGANIZATION REPORT NUMBER(S) BFLRF No. 267	5. MONITORING ORGANIZATION REPORT NUMBER(S)
6a. NAME OF PERFORMING ORGANIZATION Belvoir Fuels and Lubricants Research Facility (SwRI) 6b. OFFICE SYMBOL (If applicable)	7a. NAME OF MONITORING ORGANIZATION
6c. ADDRESS (City, State, and ZIP Code) Southwest Research Institute San Antonio, Texas 78228-0510	7b. ADDRESS (City, State, and ZIP Code)
8a. NAME OF FUNDING/SPONSORING ORGANIZATION U.S. Army Belvoir Research, Development and Engineering Center 8b. OFFICE SYMBOL (If applicable) SATBE-FL	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER DAAK70-85-C-0007; WD 8 DAAK70-87-C-0043; WD 2
8c. ADDRESS (City, State, and ZIP Code) Fort Belvoir, VA 22060-5606	10. SOURCE OF FUNDING NUMBERS PROGRAM ELEMENT NO. 62786 PROJECT NO. 1L762786AH20 TASK NO. 124 WORK UNIT ACCESSION NO.

11. TITLE (Include Security Classification)

Diesel Injector Fouling Bench Test Methodology (U)

12. PERSONAL AUTHOR(S)

Stavinoha, Leo L.; Yost, Douglas M.; and Lestz, Sidney J.

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15. PAGE COUNT
Interim	FROM Feb 1986 TO Jun 1992	1992 June	96

16. SUPPLEMENTARY NOTATION

17. COSATI CODES		
FIELD	GROUP	SUB-GROUP

18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)

Diesel Fuel; Fuel Instability; JFTOT; Fuel Injection; Injector Fouling Tests; DMD; Adiabatic Engine; Thermal Oxidative Stability

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

Compared to conventional compression ignition (CI) engine operation with the fuel being delivered at approximately 149°C (300°F), adiabatic engine operation potentially may deliver the fuel at temperatures as high as 260°C (500°F). Hypergolic CI engine combustion systems now in theoretical design stages will deliver fuel at temperatures approaching 427° to 538°C (800° to 1000°F). The ability of a fuel to resist formation of deposits on internal injector system surfaces is a form of thermal oxidative stability for which test methodology will be required. The Injector Fouling Bench Test (IFBT) methodology evaluated in this report will assist in defining fuel contribution to injector fouling and control of fuel thermal stability in procurement specifications. The major observations from this project have included:

- Forty-hour cyclic IFB tests employing both Bosch APE 113 and Detroit Diesel (DD) N70 injectors are viable procedures for evaluating fuel effects on injector fouling. Cyclic operation appears to be superior to

(Continued)

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT ☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT. ☐ DTIC USERS	21. ABSTRACT SECURITY CLASSIFICATION Unclassified
22a. NAME OF RESPONSIBLE INDIVIDUAL Mr. T.C. Bowen	22b. TELEPHONE (Include Area Code) (703) 704-1827 22c. OFFICE SYMBOL SATBE-FL

DD Form 1473, JUN 86 Previous editions are obsolete.

SECURITY CLASSIFICATION OF THIS PAGE
Unclassified

19. ABSTRACT

steady-state operation for both type injectors. Eighty-hour cyclic tests are more discriminating than 40-hour cyclic tests using the Bosch APE 113 injectors.

- JFTOT tests of fuels provide directional information on thermal stability-related deposits and filter plugging but show limited good correlation with IFBT DD N70 ratings, and none with IFBT Bosch APE 113 injector ratings. Deposition on injector pintles was more realistically rated by optical microscopy and Scanning Electron Microscopy (SEM) than conventional visual and bench rating methods.

- High-sulfur fuel readily caused sticking of Detroit Diesel injectors.

- Injector sticking is an important mode of injector fouling and is thought to be related to insoluble particulate formation from unstable fuel components.

This methodology is being recommended for utilization in high-temperature fuel studies (such as unstable fuel pretreatment evaluation for advanced integrated propulsion system engines requiring thermally stable fuel) that also includes methodology for evaluation of engine fuel combustion effects on injector fouling.

EXECUTIVE SUMMARY

Problems and Objectives: Compression ignition engine fuel injectors demand a certain degree of fuel thermal oxidative stability to maintain proper and expected spray quality. Injector nozzle deposits have adverse effects on engine fuel consumption, performance, efficiency, and endurance. This stability requirement becomes more demanding as the injector is operated at higher temperatures.

Objective: The objective of this program was to develop a test(s) for relating diesel fuel thermal oxidative stability to compression ignition engine injector fouling tendencies.

Importance of Project: Compared to conventional compression ignition (CI) engine operation with the fuel being delivered at approximately 149°C (300°F), adiabatic engine operation can deliver the fuel at 260°C (500°F). Hypergolic CI engine combustion systems now in theoretical design stages will deliver fuel at 427° to 538°C (800° to 1000°F). The ability of a fuel to resist formation of deposits of internal injector system surfaces is a form of thermal oxidative stability that may be related indirectly to fuel storage stability. As fuel thermal stability becomes more demanding or fuel thermal stability decreases (due to refinery processing and/or decreasing crude oil quality), methodology will be required for evaluating fuel thermal stability effects on diesel engine injector fouling. This methodology will assist in defining fuel contribution to injector fouling and control of fuel quality in procurement specifications.

Technical Approach: Injector Fouling Bench Test (IFBT) and modified Jet Fuel Thermal Oxidation Test (JFTOT, ASTM D 3241) methodology are being adapted for evaluating the thermal stability of diesel fuels. A new method for measuring the thickness of lacquer-type fuel deposits formed on test surfaces at elevated temperatures has been developed and applied to correlation of IFBT and JFTOT type tests to better understand diesel thermal stability and provide test methodology/test limit information for fuel specification consideration.

Injector fouling test parameters are varied with test fuel composition to provide a discernible data base and to assess methods for evaluating diesel fuel injector fouling propensities.

Accomplishments: Injector fouling bench test methodology utilizing the Bosch and Detroit Diesel injectors using cyclic stop flow (for heat-soak effects) and correlation to JFTOT test methodology (considered principally to be deposit volume and filter plugging at 232° and 260°C), has been evaluated. The major accomplishment of this program has been the development of methodology to evaluate fuel effects on injector fouling.

Military Impact: The methodology demonstrated in this program will be used to evaluate diesel fuel thermal stability quality related to injector fouling. These tests may eventually be used for specification procurement of ground equipment fuels and should result in component maintenance cost avoidance (i.e., hardware and man-hours).

FOREWORD/ACKNOWLEDGMENTS

This work was performed at the Belvoir Fuels and Lubricants Research Facility (BFLRF) located at Southwest Research Institute (SwRI), San Antonio, TX, during the period February 1986 to June 1992 under Contract Nos. DAAK70-85-C-0007 and DAAK70-87-C-0043 with the U.S. Army Belvoir Research, Development and Engineering Center (Belvoir RDE Center). Mr. F.W. Schaekel and Mr. T.C. Bowen, both of Belvoir RDE Center (STRBE-FL), served as the contracting officer's representatives, and Mr. M.E. LePera, chief of Fuels and Lubricants Research Division (STRBE-FL), served as the project technical monitor.

The authors acknowledge the technical assistance provided by Southwest Research Institute personnel in conducting this work. Mr. Alan F. Montemayor automated the injector fouling bench test rigs that Mr. Ken E. Hinton operated. Mr. James G. Barbee upgraded the Deposit Measuring Device and obtained U.S. Patent No. 4,791,811 for "Deposit Thickness Measurement," dated 20 December 1988. Ms. Lona A. McInnis performed all JFTOT and DMD measurements and coordinated all technical data requirements. Mr. Ronald S. McInnis developed the optical and SEM evaluation photographs. The authors also acknowledge the editorial assistance provided by Mr. James W. Pryor, Ms. Esther F. Cantu, and Ms. Lucretia A. Pierce in the preparation of the report.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF TABLES

I. INTRODUCTION AND BACKGROUND

Compression ignition engine fuel injectors demand a certain degree of fuel thermal oxidative stability to maintain proper operation and expected spray quality. Injector nozzle deposits have adverse effects on engine fuel consumption, performance, efficiency, and endurance. This stability requirement becomes more demanding as the injector is operated at high temperatures. Compared to conventional compression ignition (CI) engine operation with the fuel being delivered at approximately 149°C (300°F), adiabatic engine operation can deliver the fuel at 260°C (500°F). Hypergolic CI engine combustion systems now in theoretical design stages will deliver fuel at 427° to 538°C (800° to 1000°F). The ability of a fuel to resist formation of deposits on internal injector system surfaces is a form of thermal oxidative stability that may be related indirectly to fuel storage stability.

Historically, injector fouling tests developed to correlate with fuel instability have not been very successful. At a 1958 symposium (later reported in STP 244) (1)*, MacDonald and Jones reported on an injector test, stating that:

> "Test fuel is passed through motor-operated, GM series 71 unit injectors at fuel flow rate of 1.6 mL per minute at a spray tip temperature of 204°C (400°F). Test cycle consists of 20 hours on test, rack injectors hot, return rack to off position, secure 4 hours, and rack cold prior to starting next 20-hour cycle. Continue cycles until injector sticks. **Comments**--at 204°C (400°F) some fuels will cause sticking in less than 20 hours. Lowering spray tip temperature to 93°C (200°F) rates these fuels satisfactory. No fuel tested to date has caused sticking at this lower temperature, which is believed to be indicative of actual engine operating temperature. One fuel which caused injector sticking at less than 20 hours at 400°F was run successfully for 1000 hours in an operating engine (Bosch-type injectors). Reproducibility was poor and did not correlate with indicated stability of barge samples."

* Underscored number in parentheses refer to references at the end of this report.

Meanwhile, work involving the thermal oxidative stability of automotive diesel fuels work was ongoing at the U.S. Army's Coating and Chemical Laboratory.(2) Fuel-oriented problems (principally stuck injectors and plugged filters) occurring in the field prompted this investigation. Because of the absence of any laboratory bench-scale techniques designed to predict these fuel filter plugging and/or injector fouling tendencies, initial experimentation was directed towards developing an accelerated thermal-oxidation technique. To establish valid test conditions, actual diesel fuel system temperatures were obtained from Engineering and Services (E&S) test programs and also monitored under road dynamometer testing. A second attempt involved the use of an American Society for Testing and Materials-Coordinating Research Council (ASTM-CRC) Fuel Coker, which was operated in a recycle mode to simulate the geometry of automotive diesel fuel systems. Initial experiments with this technique revealed its ability to differentiate diesel fuel quality in terms of thermal-oxidative stability. Since it was evident from the first study that fuel temperature profiles were changing the quality of diesel fuel under relatively short times of operation, a program was initiated with the Materials Test Directorate (MTD) to develop a laboratory capability for evaluating this fuel characteristic.(3) To accomplish this task, a laboratory rig was utilized to more closely simulate those environmental conditions prevailing in diesel fuel injector systems. A commercial fuel injector pump calibrating stand (Model SP8100D) located within the MTD facility was modified to permit the use of GMC 53 unit injectors. To provide differentiation between satisfactory and unsatisfactory fuels, the injector test stand was further modified as follows:

1. Heaters with adjustable temperature controls [above 93°C (200°F)] were installed in the fuel sump and return fuel line.

2. Fuel sump capacity was increased to at least 20 gallons, and a variable speed drive was installed.

3. A diverter valve was installed on the injector effluent line.

In order to differentiate fuel quality, the fuel injector pump calibrating stand was instrumented to monitor the following fuel temperatures:

1. Fuel in sump
2. Fuel to filter
3. Fuel to injector
4. Fuel from injector
5. Fuel to return sump.

Pressure differential across the test fuel filter was measured to define occurrences to filter plugging. Also, the injector fuel flow rate was measured to determine any change in output due to injector fouling. The injector stand was operated at 2200 rpm to simulate full load engine operation, and the fuel temperature to the filter was maintained at 107° to 116°C (225° to 240°F).

To determine if this technique could, in fact, differentiate between fuels with different thermal-oxidation stability, three different fuels were subsequently evaluated. The first was a diesel fuel conforming to VV-F-800a grade DF-2, which was obtained from the MTD main fuel dispensing tank and was used for test equipment setup and preliminary testing. The other two samples were fuels that had exhibited fuel filter-plugging or some degree of injector seizure/fouling tendency. More specifically, one sample of DF-2 had been obtained from Camp Pendleton, a U.S. Marine Corps facility in which injector sticking problems had occurred during field maneuvers.(4) The other sample, also a DF-2, was obtained from a U.S. Air Force Strategic Air Command Minuteman installation in which excessive filter plugging had occurred during a normal emergency power generation operating procedure.(5) In subsequent evaluations of the last two fuels in this modified injector stand, there was no manifestation of fuel filter plugging nor injector fouling. However, chemical analyses of the fuel samples before and after the individual tests revealed significant increases in existent gum proportional to the duration of the test. In recent reviews of accelerated stability techniques for diesel fuels (6,7), the authors have implied that steam jet gum may be related to injector deposit/fouling and combustion chamber deposits. However, in a review of diesel fuel deterioration and related problems in 1977 (8) and later at a 1980 Symposium (9), most Army diesel fuel system problems were reported as being plugged primary fuel filters. This understanding had led to a major activity in preventing diesel fuel stability-related problems.

A number of reports related to open-type diesel injection nozzles have been published.(10-13) For evaluating fuel additive concentrates on the removal of indirect (pintle, chip, and poppet nozzle) injector deposits, Olsen, et al. (11) developed a modification of the ISO 4010 airflow test. The ISO 4010 is an international standard for calibrating delay pintle-type nozzles. In a 1984 report (12), it was indicated that the properties of diesel fuels have changed distinctly, especially in the United States. Fuel-related problems, such as passenger car diesel engine prechamber injector nozzle coking, have arisen due to deteriorated diesel fuel qualities.(12)

The short-term effects of an oxidatively unstable diesel fuel were investigated in a 1982 General Motors 4.3-L V-6 diesel car with CAV poppet-type injectors.(13) Frequent severe fuel filter plugging was found to cause poor drivability and excessive smoke, which is usually attributed to injector coking. The level of injector coking was insufficient to cause adverse measurable effects on vehicle performance.

For Cummins PT fuel system direct injectors, a laboratory engine test has been developed based on field data describing the driving cycle (which is significantly related to downhill engine braking) resulting in deposits.(14) The test was shown to be effective for evaluating fuel quality effects.(14)

In 1985, a rapid injector fouling test was reported using a John Deere T4239 four-cylinder industrial diesel engine with Roosamaster pencil-type direct injection nozzles.(15) The tests of vegetable oil fuels resulted in all injectors exhibiting deposits in a crater-like manner on the outside tip, especially around the orifices.(15)

More recently, stringent Federal exhaust emission regulations for 1994 heavy-duty diesel engines have prompted a renewed interest in diesel combustion and emissions research to find ways to reduce particulates and NO_x to the required levels.(16) Exhaust emissions from a diesel engine are highly dependent on the combustion process, which is influenced by the design of the combustion chamber as well as the fuel injection system.(16) Diesel fuel quality can adversely affect many of the parameters involved in the design of high quality fuel injection systems through time dependent deposit formation.

In late 1981 and early 1982, while screening high-temperature adiabatic lubricant candidates in a modified CLR-diesel (CLR-D) direct injection engine, personnel at Belvoir Fuels and Lubricants Research Facility (BFLRF), Southwest Research Institute (SwRI), occasionally observed fuel injector fouling. The modified CLR-D was operated uncooled in the cylinder liner area with 149°C (300°F) coolant temperature in the head. Fouling of the Bosch APE 113 fuel injector occurred as plugged injector holes, resulting in erratic engine operation. A brief investigation was conducted to determine if the injector fouling was related to fuel properties. The results of the screening were encouraging for developing a methodology of determining injector fouling tendencies of diesel fuels of varying storage stability quality. A program was initiated in September 1982 to develop a combustionless bench test for injecto. fouling evaluations of diesel fuel, and the results were reported in 1986.(17,18) Two injector fouling bench test rigs were developed, one of which uses the same CLR-D engine no-fuel return injector, while the other rig uses a high-fuel return injector common to many high-performance diesel engine fuel injection systems. References 17 and 18 summarize Injector Fouling Bench Tests (IFBT) and modified Jet Fuel Thermal Oxidation Tests (JFTOT), ASTM D 3241 data, which were used to develop methodology for evaluating the thermal stability of diesel fuels.

The Jet Fuel Thermal Oxidation Test (JFTOT), ASTM D 3241, has been used for many years to evaluate thermal stability of aviation fuels. The available ASTM methods for rating deposits on JFTOT test tubes consist of a subjective visual rating method, that attempts to match the deposit to one of five color standards. A photo-optical approach is also used (the tube deposit rater, TDR), that measures attenuation of a beam of light that passes through the deposit, is reflected by the tube's surface, exits through the deposit, and is detected by a photocell. Modification of the JFTOT apparatus and procedure to evaluate thermal stability of diesel fuels and crankcase lubricants have expanded the utilization of this expensive apparatus. However, the standard deposit-measuring devices are quantitatively inadequate. The essential problem results from the fact that diesel fuels and lubricants form deposits with thickness so great that the optical system is ineffective in measuring deposit volume.

In a 1983 cooperative Belvoir RDE Center/U.S. Navy project (17,19), a unique quantitative, nondestructive deposit thickness-measuring technique was devised in support of the diesel fuel

injector/thermal fouling bench test development. Based on an excellent correlation of 350 volts (dielectric breakdown) with a 1.0-μm deposit thickness for a 1-percent sulfur referee fuel, this technique is applied to deposits from other test fuels and is used to calculate deposit thickness and volume. This test methodology was incorporated into a prototype testing device. This Deposit Measuring Device (DMD), actuated by a manually operated switch, gently lowers the electrode onto the deposit, applies increasing voltage, detects dielectric breakdown, displays that detected voltage, and lifts the electrode off the manually indexed test tube.

These combined IFBT and quantitative JFTOT capabilities could now be utilized in a program to evaluate diesel fuel composition related to thermal oxidative stability and injector fouling relationships.

II. OBJECTIVE

The objective of this program was to develop a test(s) for relating diesel fuel thermal oxidative stability to compression ignition engine injector fouling tendencies. These data would be used to define a method for predicting fuel injection depositing phenomena.

III. EXPERIMENTAL APPROACH

Injector fouling bench test rigs were used with various test fuels in an effort to create measurable injector fouling. Injector inspection included the DMD for pintle deposit quantitation, nozzle airflow for sac hole plugging, and standard injection rating techniques.

A. Deposit Measuring Device

In the current project, the Deposit Measuring Device (DMD) developed and reported in References 17 and 19 was further modified to include:

1. New ramping electronics including assembly language programming allowing ramping at rates of 1 millisecond to 10 seconds over a range of 0 to 1500 volts.

2. An outboard Deposit Measuring Device electrode module was utilized to evaluate deposits on pintles from injectors subjected to injector fouling bench tests.

This modified version of the DMD was used in this study as well as to provide DMD data as reported by Morris and Hazlett in 1989.(20) The DMD data in Reference 20 showed a good correlation to carbon burn-off values and deposit volumes calculated by an interferometric technique. Based on deposit density calculations, assuming that a density value of 1.0 to 1.5 g/cm^3 is reasonable, deposit volumes greater than 0.0800 mm^3 (and ranging up to 0.6365 mm^3) by DMD seemed most reliable in this work. These DMD deposit volumes correspond to carbon burn-off values of 95 μg to 877 μg of carbon, respectively.

B. Injector Fouling Bench Test

The Injector Fouling Bench Test (IFBT) apparatuses reported in Reference 17 were modified to allow higher temperature [316°C (600°F)] controlled heating of the nozzle tip heating block. Also the fuel-handling systems of both rigs were converted to stainless steel for ease of cleaning and elimination of possible metallic fuel contamination. Using a 1-percent sulfur referee test fuel meeting Specification MIL-F-46162B, IFB Test Nos. 6, 8, and 9 (labeled 6-B, 8-B, and 9-B for Bosch injector and 6-D, 8-D, and 9-D for Detroit Diesel injector) were completed using continuous and cyclic fuel spray at nozzle tip heating block temperatures of 316°C (600°F) and 293°C (560°F) for the Detroit Diesel and Bosch injector, respectively. The cyclic tests consisted of 15-minute spray periods followed by 15-minute no-spray (heat soak) periods. During the heat soak periods, the fuel spray thermocouple readout showed increased temperature, indicating a heat increase occurring when the fuel flow stopped. Visual examination of the injector pintle showed much higher deposits with the cyclic test. When the tip heating blocks were reduced 50°F, the IFB Test Nos. 9-D and 9-B showed reduced deposits more equivalent to the higher temperature continuous spray results.

Based on results of the cyclic test, the IFBT rigs were modified for automated operation. Inspection data for IFB Test Nos. 6, 8, and 9 are provided in Section IV, Results. Fig. 1 is a schematic of the CRL-D Bosch Injector Fouling Bench Test apparatus.

The Detroit Diesel (DD) IFBT apparatus was developed to determine the injector deposition tendencies of the DD 6V-53T (N70) unit injector. The unit injector contains the metering/pressurizing assembly and nozzle in a single unit; thus, the bypassed fuel is exposed to high injector temperatures. Fig. 2 is a schematic of the Detroit Diesel IFBT apparatus. The interest in developing the DD rig spawned from the high fuel return rates of the unit injector in which the fuel is used to cool the injector in the cylinder head. The high recycle rate and the additional thermal stressing of the fuel are considered important factors governing the pintle deposition with the DD rig.

The Detroit Diesel Injector Fouling Bench Test apparatus was modified to incorporate automatic on-off cycling. This modification was much simpler to perform than the Bosch apparatus, requiring only the addition of a cycle timer and digital speed indicator. Fig. 3 depicts the modified test apparatus, and Appendix A includes detailed IFB test procedures for the Detroit Diesel IFBT apparatus.

Additions to the Bosch IFBT apparatus included an independent variable speed drive, automatic on-off controller, digital speed indicator, and a new test stand. These modifications served to minimize operator time as well as to make the rig portable, more versatile, and much easier to conduct the cyclic on-off operation required for simulating field shutdown soak back effects. This action also eliminated the need for the Unitest machine, which had previously been used as the variable speed drive. Fig. 4 depicts the modified test apparatus, and Appendix B includes the detailed IFB test procedures for the Bosch APE 113 IFBT apparatus.

Both rigs now have the capability of manual control or automatic on-off cycling. With the unmodified rig, this cycling required extensive operator interaction and introduced a source of potential error.

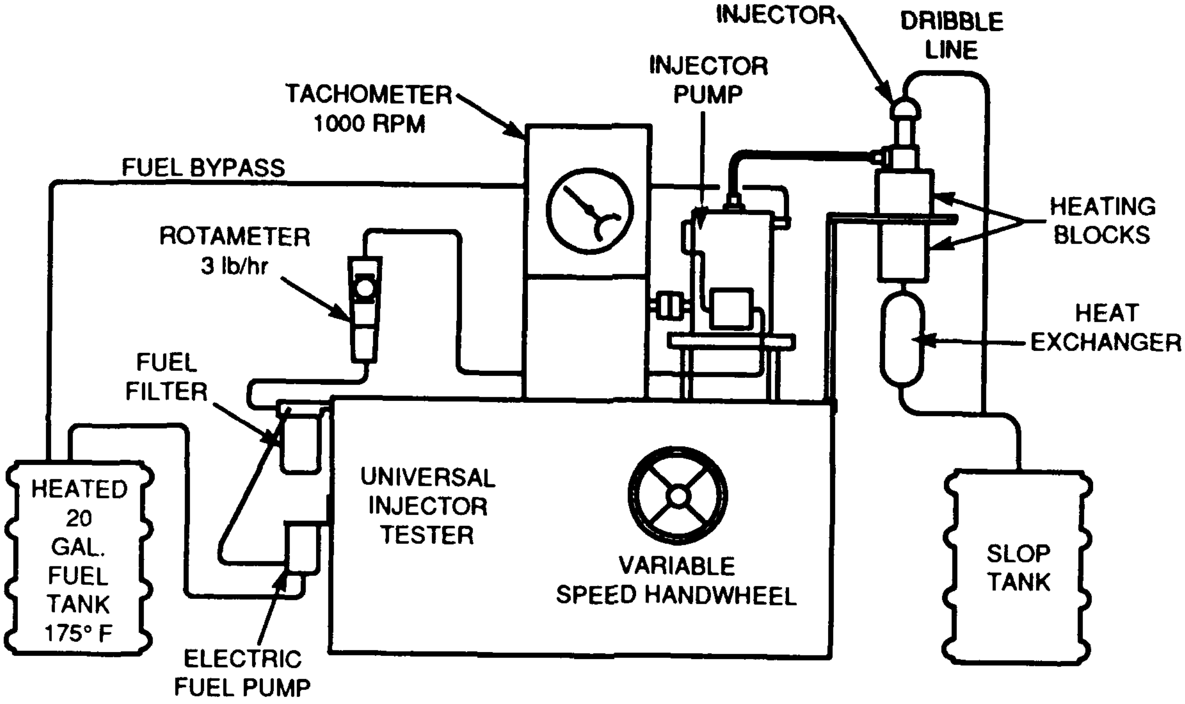


Figure 1. <u>CLR-D Bosch injector fouling bench test apparatus</u>

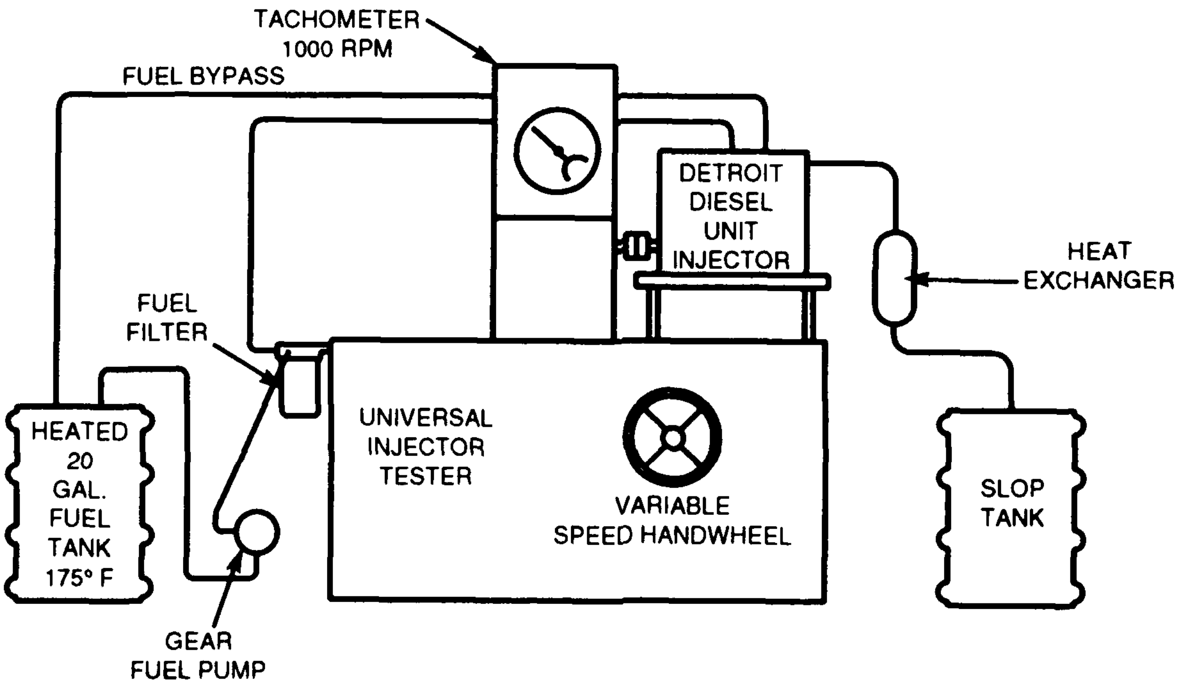


Figure 2. <u>Detroit Diesel injector fouling bench test apparatus</u>

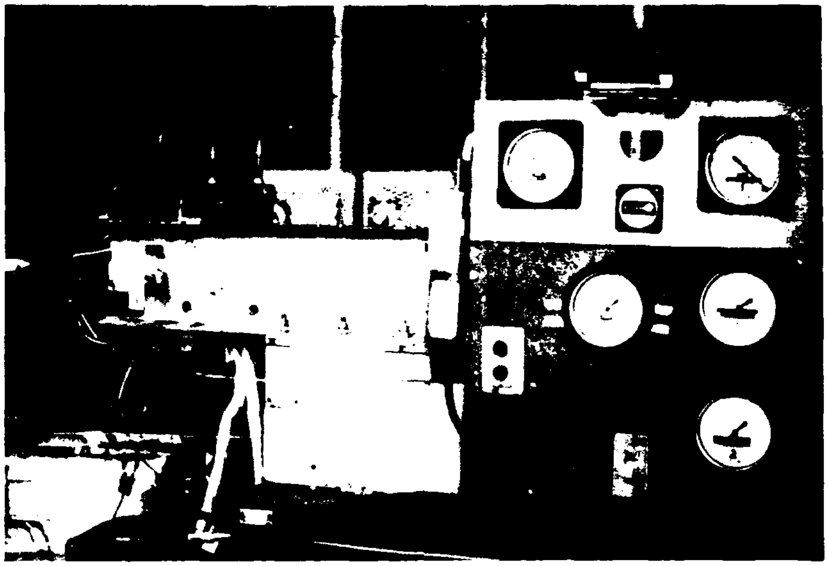


Figure 3. Modified Detroit Diesel injector fouling bench test apparatus

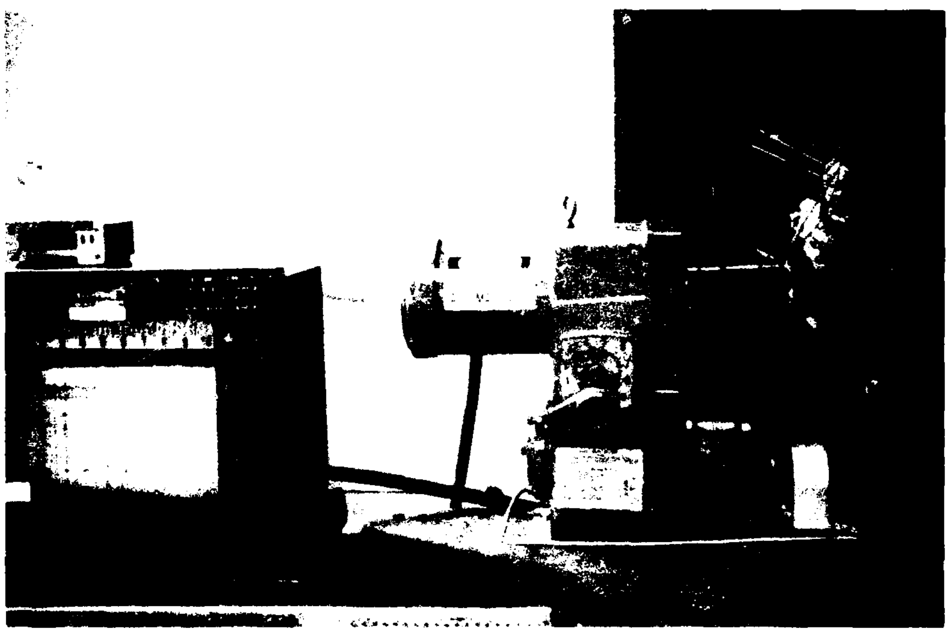


Figure 4. Modified CLR-D Bosch injector fouling bench test apparatus

The deposits of the injector needle were rated in three areas--the needle tip, the nonrubbing shaft, and the rubbing area. These areas are illustrated in Fig. 5. The method for rating the injector needle utilizes the CRC brown lacquer merit scale normally used for rating engine deposits. These areas were also evaluated by the DMD as a measure of deposit thickness.

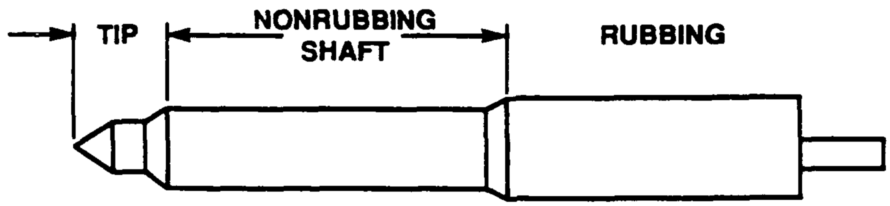


Figure 5. Areas of injector needle rated for deposits

C. Test Fuels

TABLE 1 lists fuel code numbers, fuel type, origin, date received, and method of fuel storage/procurement. The last column in TABLE 1 identifies the IFB test number in which the fuel was used. The neutral, acid, and peroxide ingredients identified in TABLE 2 were selected from a patent [U.S. Patent No. 4,330,302, "High Thermal Stability Liquid Hydrocarbon and Methods For Producing Them," (21)] as materials that can reduce fuel thermal stability. TABLE 2 identifies the components and concentration of chemicals used to prepare diesel fuel samples containing components of Test Blend Nos. 1 through 5. Strong acids such as naphthalene sulfuric acid (identified in Reference 22 as a major reactant for insolubles formation) were not used in this work due to its high reactivity.

Analyses of fuels before and after IFBT runs have included the following tests:

- Potential Insolubles: D 2274, "Test Method for Oxidation Stability of Distillate Fuel Oil (Accelerated Method)."
- Particulates: D 2276, "Test Methods for Particulate Contaminates in Aviation Turbine Fuels."
- Gum: D 381, "Test Method for Existent Gum in Fuels by Jet Evaporation."

TABLE 1. Test Fuels for Injector Fouling Bench Test

Fuel Code Number	Fuel Type	Fuel Origin	Date Fuel Received	Fuel Storage	IFB Test No.
AL-12624-F	1% Sulfur (A) MIL-F-46162B	Refinery	01/06/84	Tank	6, 8, 9
AL-15482-F	Ref. No. 2 Diesel	Refinery, AL-15218-F	07/08/86	Tank	12
AL-15542-F	1% Sulfur MIL-F-46162C without stabilizer additive	Refinery	11/19/86	Drum No. 4	15, 16, 28
AL-16127-F	Jet A	Distribution	06/09/87	Tank	17
AL-16823-F	AL-16127-F + 3% TBDS (B)	Blend	--	Drum	13
AL-17204-F	Ref. No. 2	Refinery	02/04/88	Drum	14
AL-18516-F	Ref. No. 2	Refinery	02/09/89	Drum	18, 19
AL-18649-TB2	AL-18516-F + Test Blend No. 2 Components	Blend	--	Drum	20
AL-18649-TB4	AL-18516-F + Test Blend No. 4 Components	Blend	--	Drum	21
AL-18954-F	90% AL-18516-F + 10% LCGO (C)	Blend	--	Drum	22
AL-18987-F	Ref. No. 2	Refinery	08/11/89	Drum	26
AL-19053-F	AL-18987-F + 0.35% MFO (D)	Blend	--	Drum	23
AL-19062-F	JP-8	Ft. Bliss	10/23/89	Drum	24
AL-19393-F	JP-8	Refinery	06/12/90	Drum	27
AL-19444-F	1% Sulfur MIL-F-46162C without stabilizer additive	Refinery, AL-15542-F	11/19/86	Drum No. 5	29
FL-1325-F	3 Parts Burner Oil + 1 Part Additive	Manufacturer	10/06/87	Drum	25

(A) Treated with 25 lb/1000 bbl FOA-15.
(B) di-*tert*-butyl disulfide.
(C) Light Coker Gas Oil (FL-1440-F).
(D) Marine Fuel Oil (FL-0348-F).

TABLE 2. Ingredients for Increasing Diesel Fuel Fouling

	Test Blend No. 1		Test Blend No. 2		Test Blend No. 3*		Test Blend No. 4		Test Blend No. 5	
	Treat Rate per Liter of Fuel†									
	vol %	mL/L	vol %	mL/L	vol %	mL/L	vol %	mL/L	vol %	mL/L
Group I: Neutrals										
Group IB:										
1) 1-Dodecene	0.2	2	0.2	2	0.2	2	0.2	2	0.2	2
2) Cyclohexene	0.1	1	0.1	1	0.1	1	0.1	1	0.1	1
3) alpha-Methylnaphthalene	0.1	1	0.1	1	0.1	1	0.1	1	0.1	1
4) alpha-Methylstyrene	0.2	2	0.4	4	0.4	4	0.4	4	0.4	4
5) Indene	0.2	2	0.4	4	0.4	4	0.4	4	0.4	4
	mg KOH/g	g/L	mg KOH/g	g/L	mg KOH/g	g/L	mg KOH/g	g/L	mg KOH/g	g/L
Group II: Acids										
Group IIA:										
2) Cyclohexanecarboxylic Acid	0.025	0.0494	0.025	0.0494	0.025	0.0494	0.025	0.0494	0.025	0.0494
3) Naphthenic Acids	0.025	0.0786	0.025	0.0786	0.025	0.0786	0.025	0.0786	0.025	0.0786
4) Decanoic Acid	0.025	0.0664	0.025	0.0664	0.025	0.0664	0.025	0.0664	0.025	0.0664
							ppm	mL/L	ppm	mL/L
Group III: Peroxides										
1) t-butylhydroperoxide (TBHP)							100	0.2639	300	0.7917

***Test Blend No. 2 plus 100 ppb copper (using copper cyclohexane butyrate).**
†Procedure:
To one liter of diesel fuel:
1. Add one at a time in stirred glass vessel to observe solubility.
2. Let set overnight (minimum) in dark storage and observe any sign of incompatibility.
3. If all appears soluble/compatible, proceed with testing.

- Carbon Residue: D 524, "Test Method for Ramsbottom Carbon Residue of Petroleum Products."
- Color: D 1500, "Test Method for ASTM Color of Petroleum Products (ASTM Color Scale)."
- Acids: D 664, "Test Method for Acid Number of Petroleum Products by Potentiometric Titration."
- Stability by Oxygen Overpressure: Same as ASTM D 873 but using insolubles by D 2276.
- JFTOT: D 3241, "Test Method for Thermal Oxidation Stability of Aviation Turbine Fuels (JFTOT Procedure)."

D. Nozzle Airflow Tester

An injector airflow tester based on International Standard ISO 4010-1977 (E) (23) was modified by incorporating a bell jar cover over a metal plate to accommodate CLR-D Bosch and DD injector nozzle bodies. The schematic of the modified tester is shown in Fig. 6. This test procedure, included as an attachment in both Appendices A and B, provided a means of measuring nozzle tip spray hole plugging.

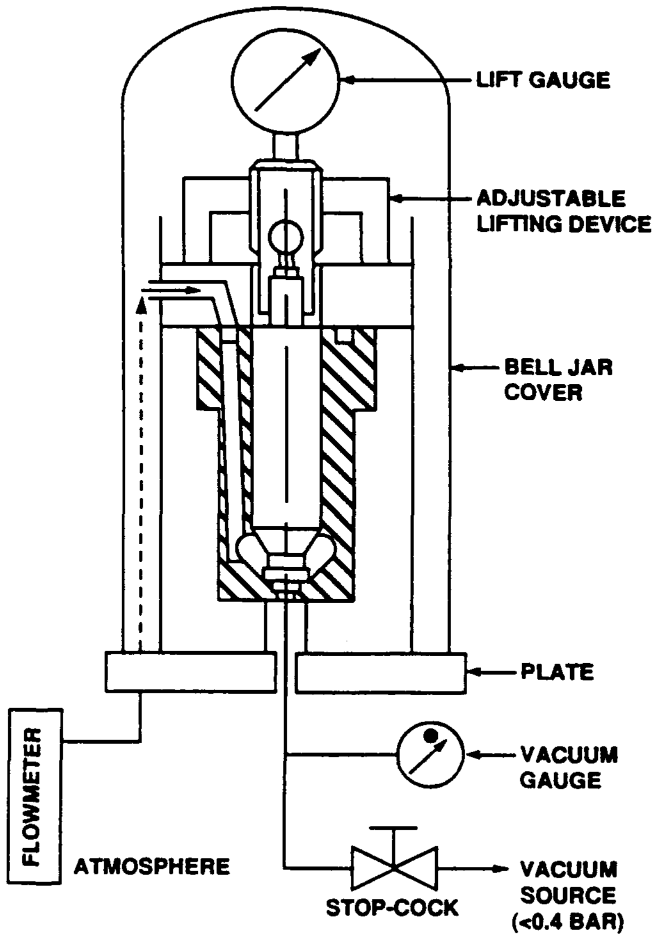


Figure 6. Modified airflow tester schematic

IV. RESULTS

The IFB test data are summarized in Appendix C. TABLE C-1 of Appendix C presents data for the Detroit Diesel (DD)

injectors and TABLE C-2 gives data for the Bosch injectors. While Set 1 in TABLES C-1 and C-2 is the data obtained before the IFBT rigs were automated, Sets 2 and 3 were obtained after the IFBT rigs were automated. The principal difference between IFB Test Data Sets 2 and 3 was a lower DD nozzle tip heating block temperature. The nozzle tip heating block control temperatures were 316°C (600°F) and 293°C (560°F) for the DD and Bosch IFBT rigs, respectively, in Set 2 other than test 16 that was 288°C (550°F) for the DD rig and 260°C (500°F) for the Bosch rig, and 288°C (550°F) and 293°C (560°F), respectively, in Set 3 [other than for the first test (No. 18-D), which was 316°C (600°F)].

TABLES C-3 and C-4 of Appendix C provide fuel analysis data before and after IFB tests, respectively. Note that the test number followed by a "D" or a "B" designates Detroit Diesel and Bosch injectors, respectively. TABLE C-5 of Appendix C summarizes the ASTM D 2274 accelerated stability test data as compared with JFTOT D 3241 type thermal stability data. The JFTOT D 3241 data include DMD and D 3241 deposit ratings for selected test fuels and fuel blends. TABLE C-6 (Appendix C) summarizes 150°C accelerated stability data of selected fuels before and after IFB Test Nos. 18 through 29.

V. DISCUSSION OF RESULTS

The IFBT results reported in TABLES C-1 and C-2 of Appendix C are divided into three test sets:

- Test Set 1: Used one test fuel to establish or select injector cyclic operation temperatures for the injector nozzle tip heaters block.
- Test Set 2: Compared the effects of fuel sulfur concentration on injector nozzle fouling.
- Test Set 3: Used 40-hour and 80-hour cyclic tests in an effort to foul injectors and correlate fouling with JFTOT test results or other fuel properties.

The first set (IFB Test Nos. 6, 8 and 9) were used as a basis to modify the IFBT rigs (reported in References 17 and 18) to cyclic operation. The test conditions used a 1-percent sulfur referee

diesel fuel meeting Specification MIL-F-46162 and were performed under continuous spray conditions (IFB Test No. 6-B) and cyclic spray (15 minutes on, 15 minutes off) conditions (IFB Test Nos. 8-B and 9-B). The Bosch APE 113 and DD N70 injector nozzle tip heating blocks were maintained at temperatures of 293°C (560°F) and 316°C (600°F), in IFB Test Nos. 8-B and 8-D, respectively, the conditions chosen for further evaluation after automating the test rigs. Under these conditions, both nozzle tips provide a fuel spray temperature of approximately 260°C (500°F). Aviation turbine kerosene or jet fuels usually produce lower spray temperatures, which is thought to be due to higher volatility of the spray and/or lower viscosity of the fuel.

The IFB Test Set 2 data highlights (regarding fuel and comments) were:

IFB Test Set 2 Data Highlights

IFB Test No.	Fuel and Comments
12-D 12-B	Reference No. 2 Diesel Fuel (R2DF) procured in 1986.
14-D 14-B	Reference No. 2 Diesel Fuel (R2DF) procured in 1988.
15-D 15-B	1% sulfur referee fuel without additives procured in 1986. 15-D pintle stuck after only 16 hours.
16-D 16-B	1% sulfur referee fuel without additives procured in 1986. 16-D ran 40 hours with the nozzle tip temperature reduced to 550°F compared to 15-D at 600°F.
13-D 13-B	Jet A + 3% sulfur (from di-*tert*-butyl disulfide). 13-D pintle stuck in 3.25 hours; 13-B pintle stuck in 15.5 hours.
17-D 17-B	Jet A base fuel used in 13-D and 13-B.

The test fuel in IFB Test Nos. 13 and 17 was used in a U.S. Army 210-hour wheeled-vehicle test cycle modified such that Jet A fueled the DD 3-53 engine No. 1 cylinder and Jet A plus 3 percent S (from di-*tert*-butyl disulfide) fueled cylinder Nos. 2 and 3.(24) Injector Nos. 2 and 3

3 percent S (from di-*tert*-butyl disulfide) fueled cylinder Nos. 2 and 3.(24) Injector Nos. 2 and 3 fouled after 175 hours of operation. Scanning Electron Microscopy (SEM) examination showed corrosive pitting of the fouled injector tips and deposit on the rubbing and nonrubbing surfaces of its pintles. The IFB Test Nos. 13-D and 13-B test pintles were analyzed by Auger, SEM, and Fourier Transform Infrared Spectroscopy revealing the deposit to probably be iron sulfate (possibly derived from iron other than the pintle). IFB Test Nos. 17-D and 17-B (which used Jet A) showed only thin lacquer-type deposits. Fig. 7 photographically shows, at 20X, the scale deposit on 50 percent of the nonrubbing area of the Bosch pintle from IFB Test No. 13-B. This scale deposit is attributed to the sulfur compound added to the Jet A base fuel. Fuel analysis data in TABLES C-3 and C-4 (Appendix C) did not significantly differentiate between the two fuels.

Batches of Reference No. 2 diesel fuel (R2DF) procured during and after 1988 have not been as unstable as batches procured prior to 1988 in this and other stability programs. Visually, the IFB Test No. 12

Figure 7. Photograph (20X) of IFB Test No. 13-B injector pintle
(Upper half of nonrubbing shaft and tip)

(Fuel No. 15482, procured in 1986) injector pintles had more deposits than IFB Test No. 14 (Fuel No. 17204, procured in 1988) injector pintles had more deposits than IFB Test No. 14 using R2DF fuels. TABLE 3 is a brief summary of the results, indicating the difference in stability of the two Reference No. 2 diesel fuel batches.

TABLE 3. Comparison of Two Batches of Reference No. 2 Diesel Fuel

Fuel Code	Test No. 12 15482	Test No. 14 17204
Pintle Merit Rating: Total (30 = Clear)		
DD	5.2	4.7
Bosch	9.9	12.8
JFTOT Breakpoint, °C	250	250
DMD at 260°C, cc × 10^{-7}	151	<50
D 2274, mg/100 mL	6.7	1.2

The IFB Test No. 15 using 1-percent sulfur referee fuel without stabilizer additive resulted in a stuck pintle in the DD IFBT rig at 16 hours. The Bosch IFB Test No. 15-B ran 40 hours, after which the pintle showed high deposits. In IFB Test No. 16, the DD IFBT rig was run at nozzle tip heater temperature of 288°C (550°F), while the Bosch IFBT rig was run at 260°C (500°F). Both rigs completed 40 hours. Deposit level was high on the IFB Test No. 15-B pintle, with much less deposit on the IFB Test No. 16-B pintle, thus reflecting the deposition influence of the lower nozzle tip heater block. However, the merit ratings for the 15-B and the 16-B pintles were essentially equivalent at 9.7 and 11.3, respectively. Thus, the pintle merit ratings did not differentiate between the deposit level on the pintles. Nozzle body airflow tests did not reveal any significant nozzle tip blockage as the airflow values did not vary significantly.

The IFB Test Set 3 data highlights (regarding fuel and comments) were:

IFB Test Set 3 Data Highlights

IFB Test No.	Fuel and Comments
18-D 18-B	Reference No. 2 Diesel Fuel (R2DF) procured in February 1989. IFB Test No. 18-D Nozzle Tip Heater Block at 600°F (the rest of this set at 550°F).
19-D 19-B	Reference No. 2 Diesel Fuel (R2DF) procured in February 1989.
20-D 20-B	R2DF + Blend No. 2.
21-D 21-B	R2DF + Blend No. 4.
22-D 22-B	R2DF + 10 vol% Light Coker Gas Oil (LCGO).
23-D 23-B	R2DF + 0.35 vol% Marine Fuel Oil (MFO).
24-D 24-B	JP-8 (Ft. Bliss, TX).
25-D 25-B	3 parts burner oil + 1 part additive.
26-D 26-B	R2DF Batch procured August 1989. Eighty-hour cyclic test.
27-D 27-B	JP-8 (San Antonio, TX Refinery). Eighty-hour cyclic test.
28-D 28-B	1% sulfur without additives procured in November 1986. Eighty-hour cyclic test. 28-D pintle stuck at 36.5 hours (Drum No. 4).
29-D 29-B	1% sulfur without additives procured in November 1986 (Drum No. 5). Eighty-hour cyclic test. 29-B test ran for 40 hours as a comparison with 28-D.

IFB Test Nos. 18 through 24 were scheduled for 40-hour cyclic operation, while the last four tests were aimed at 80-hour cyclic operations to achieve higher injection deposit discrimination.

The primary objective of IFB Test Nos. 18 through 24 was to observe and correlate a wide degree of injector fouling versus fuel thermal stability as measured by JFTOT test results and other stability-related properties of the fuels.

Using selected fuel data from TABLE C-5 (Appendix C), Fig. 8 demonstrates various JFTOT tube deposit volumes (by DMD measurements) under D 3241 standard test conditions at 260°C, compared with the fuel recirculated (and stirred in the D 3241 reservoir). Also provided in Fig. 8 are JFTOT breakpoint temperatures (BPT) relating estimated Code 3 inception temperatures.

Fig. 9 demonstrates the fuel JFTOT breakpoint temperature (BPT), Code 3 inception temperature, and relationship to JFTOT heater tube deposit volume measured by DMD. Note the high deposit volumes for the fuels with BPTs of 215°C.

The test blend numbers in TABLE C-5 (Appendix C) and the blend numbers in Fig. 8 refer to the five different test blend combinations and fuel treat rates defined in TABLE 2. These blends were composed of ingredients that included hydrocarbons described as Group I: Neutrals (which included olefinic hydrocarbons), Group II: Acids (weak organic acids as opposed to strong organic sulfonic acids), and Group III: Peroxides (*tert*-butyl hydroperoxide in this work). These groups of materials have been identified as causing increased thermal deposits when present in jet fuels.(15)

Test Blend No. 2 is the same as Test Blend No. 1 except for a higher level of alpha-methylstyrene and indene. Test Blend No. 3 is the same as No. 2 except that 100 ppb copper (from copper cyclohexane butyrate) was added to the blend. Test Blend No. 4 is the same as No. 2 except for addition of 100 ppm of peroxide, and Test Blend No. 5 is the same as No. 4 but with 300 ppm of peroxide.

These blends were made with the Reference No. 2 diesel fuel (R2DF) and evaluated by JFTOT ASTM D 3241 method with some variations in the procedure and method of deposit evaluation. This included test runs with and without the 0.8-micrometer filter between the fuel reservoir and

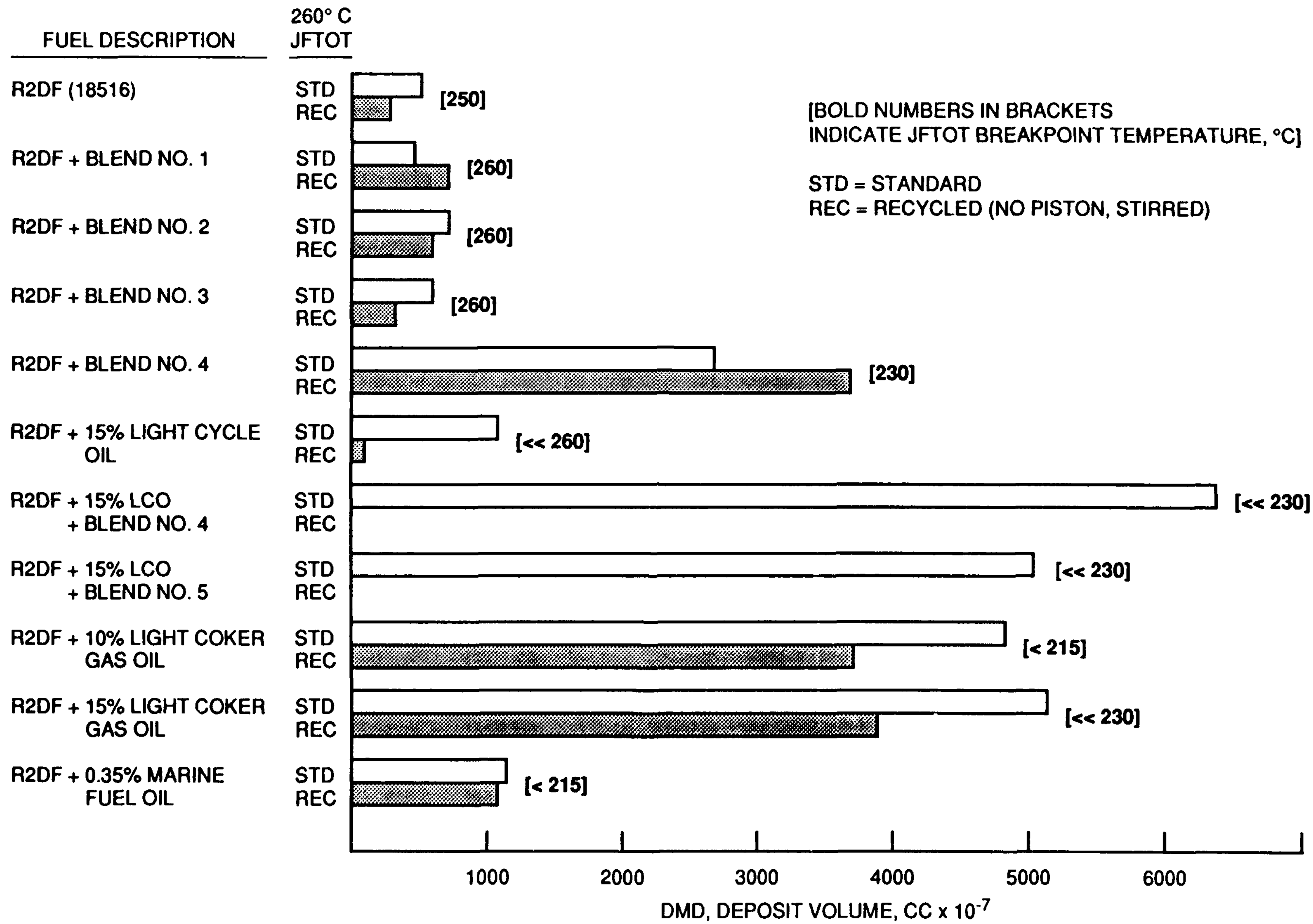


Figure 8. Effect of additives on Ref. No. 2 diesel fuel thermal stability deposit measurements

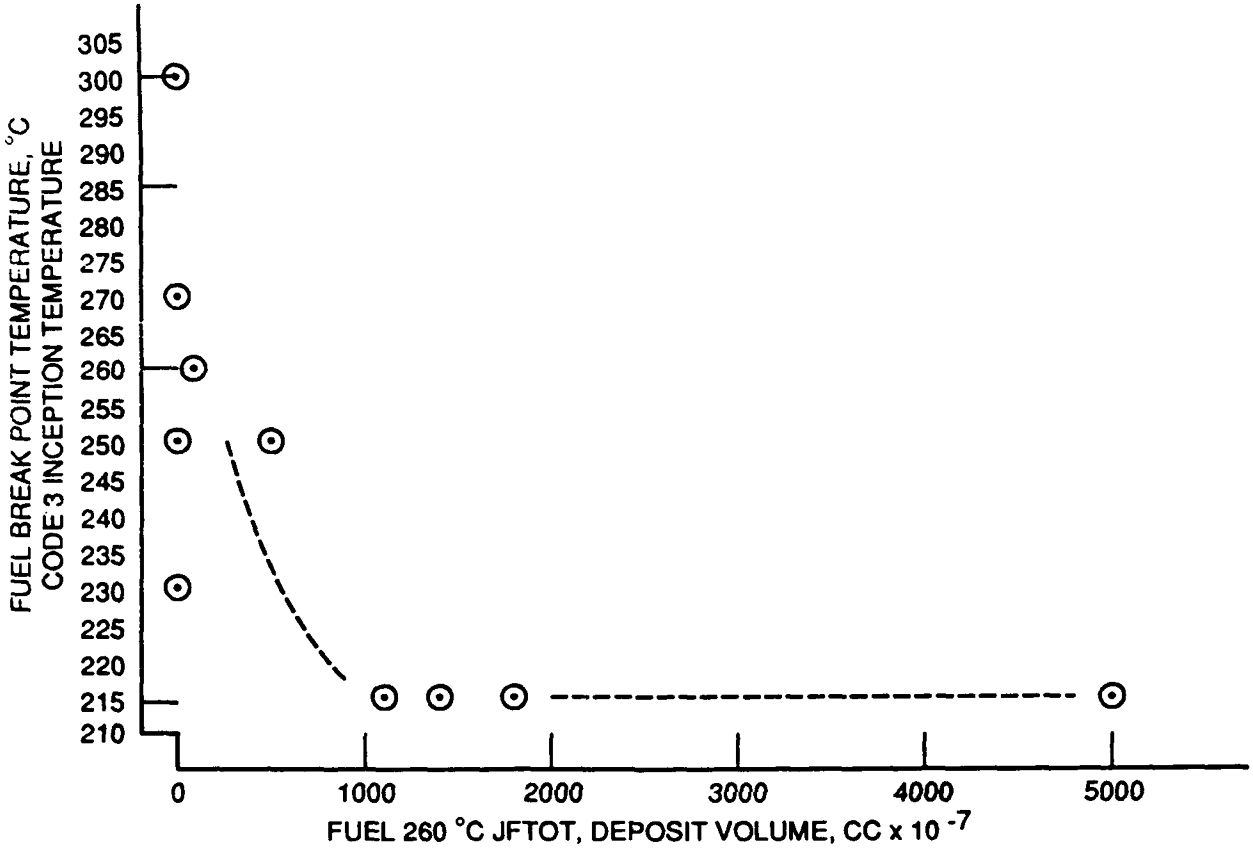


Figure 9. <u>JFTOT deposit volume as measured by DMD versus breakpoint temperature</u> (Visual Code 3 inception temperature)

the heater tube. Tests with the fuel recycled involved not installing the piston above the test fuel in the fuel reservoir and use of a magnetic stirrer in the fuel reservoir. The recycled fuel tests were designed to evaluate mixing of the heater tube effluent fuel with fuel in the reservoir to provide an indication of heated fuel recycle effects on deposit levels. The 17-micrometer steel mesh filter on the heater tube effluent was used for each test and monitored for pressure drop. This filter is routinely bypassed when the back pressure reaches 125-mm mercury.

Fig. 8 provides visual comparison of JFTOT heater tube deposit volume (measured by DMD) for tubes evaluated at 260°C with the fuel either flowing directly to the test tube (fuel reservoir piston in place) or with the fuel recycled (piston removed from the reservoir and fuel stirred). The base fuel (R2DF) in TABLE C-5 of Appendix C and Fig. 8 showed a deposit decrease and

a significant reduction in time to reach a 125-mm mercury pressure drop (at which time the stainless steel test filter is bypassed) in the fuel recycle mode at both 232° and 260°C heater tube test temperatures.

Comparison of Test Blend Nos. 1 through 4 in the R2DF fuel showed higher deposit volume levels with a dramatic increase in deposit levels for Test Blend No. 4. Comparison of deposit level using stainless steel 304 test tubes (TABLE C-5 of Appendix C) as opposed to the aluminum test tubes showed a dramatic reduction from a deposit volume of 2675 and 3683 cc $\times 10^{-7}$, with aluminum tubes, to 1159 and 1129 cc $\times 10^{-7}$, with 304 SS tube, for the direct and the recycled fuel test results. Aging of the R2DF fuel containing Test Blend No. 2 and Test Blend No. 4 (at 80°C for 1 week) resulted in dramatic reductions of the deposit volume to levels of 161 and 52 cc $\times 10^{-7}$, respectively, as shown in TABLE C-5 of Appendix C. The R2DF plus 15 percent light cycle oil raised the deposit volume to 1077 from 514 at 260°C and from 286 to 99 cc $\times 10^{-7}$ recycled fuel at 260°C. The R2DF plus 15 percent light cycle oil plus either Test Blend No. 4 or Test Blend No. 5 (described in TABLE 2) both significantly increased the 260°C deposit volume from 1077 to 6364 and 5030 cc $\times 10^{-7}$, respectively.

The most dramatic increases were with 10 and 15 percent light coker gas oil and 0.35 percent marine fuel oil, with deposit volumes of 4823, 5130, and 1141 cc $\times 10^{-7}$, respectively.

IFB Test No. 18-D was run with a new batch of R2DF at a nozzle tip heating block temperature of 316°C (600°F) for comparison to IFB Test Nos. 12-D and 14-D. As in other test programs, the stability of Reference No. 2 diesel fuel (R2DF) batches has improved with procurements in 1988 and later. See also the D 2274 stability data in TABLE C-3 (Appendix C). IFB Test No. 19-D was run at a nozzle tip heating block temperature of 288°C (550°F), which was chosen for the remainder of this set of IFB tests. Similar results were observed for the Bosch injector Test Nos. 12-B, 14-B, 18-B, and 19-B.

Using the CRC rating total for the DD pintles from TABLE 3, Fig. 10 demonstrates a general lack of agreement between the CRC merit rating and its fuel 260°C JFTOT deposit volume as

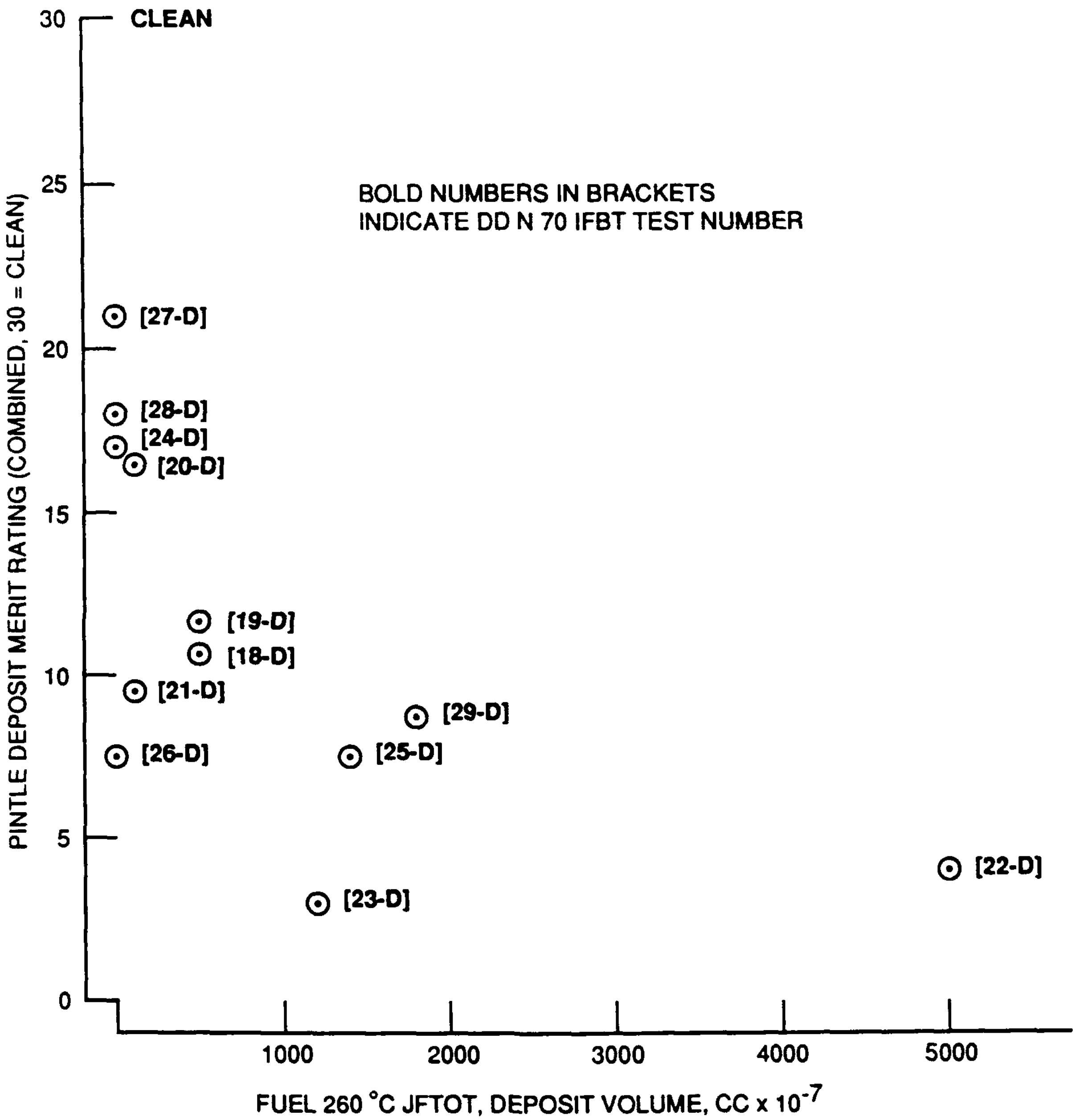


Figure 10. **<u>DD N70 injector pintle merit rating versus fuel 260°C JFTOT deposit volume for IFB Test Nos. 18-D to 29-D</u>**

measured by DMD. In Fig. 11, the same CRC pintle merit ratings are seen to generally correlate with the fuels JFTOT Breakpoint Temperature (BPT), i.e., the visual Code 3 inception temperature. No such correlation was apparent in Fig. 12 for the Bosch APE 113 injector pintles.

DMD deposit measurements for the injector pintles seemed to be very low compared to the visual appearance of many of the injector pintles, which may have indicated that the deposits were electrically conductive.

At the end of every IFB test, each of the injectors was checked with fuel for spray pattern, injector pressure, and (for DD injector) fuel flow and leak down delta pressure. The airflow test (a variation of ISO 4010-1977E) requires a vacuum on the nozzle and movement of the pintle to various locations. If the pintle is stuck (too difficult to move), the injector airflow is measured with the pintle removed. A stuck pintle was often the case due to a buildup of deposit (to varying degrees) on the rubbing surface of the pintles. No correlation seemed apparent between stuck pintles and pintle merit rating. Other than for IFB Test Nos. 19-D and 29-D, the airflow test did not seem to reveal any high degree of injector nozzle tip fouling. With the exception of IFB Test Nos. 28-D and 29-D, these injector evaluation tests generally revealed no injector fouling.

It was at this point that it was deemed necessary to look closer at the injector pintles by optical and SEM methods. Fig. 13 provides optical microscopic (4X) photographs of both Bosch APE 113 and DD N70 pintles from IFB Test Nos. 15, 16, 26, 27, 28, and 29. Also shown in parentheses in Fig. 13 are the CRC merit ratings (10 = clean) for the nonrubbing areas of the pintles.

To further emphasize the lack of DMD sensitivity to pintle deposit measurement and the visual deposit merit ratings, SEM photographs in Figs. 14 through 17 are provided for pintles from IFB Test Nos. 15-D, 16-D, 27-D and 29-D, and Figs. 18 and 19 for IFB Test Nos. 27-B and 29-B, respectively. Note the very clean appearance of the pintle of IFB Test No. 27-B compared to the flaky surface of the pintle of IFB Test No. 29-B. Flake edge measurement optically showed

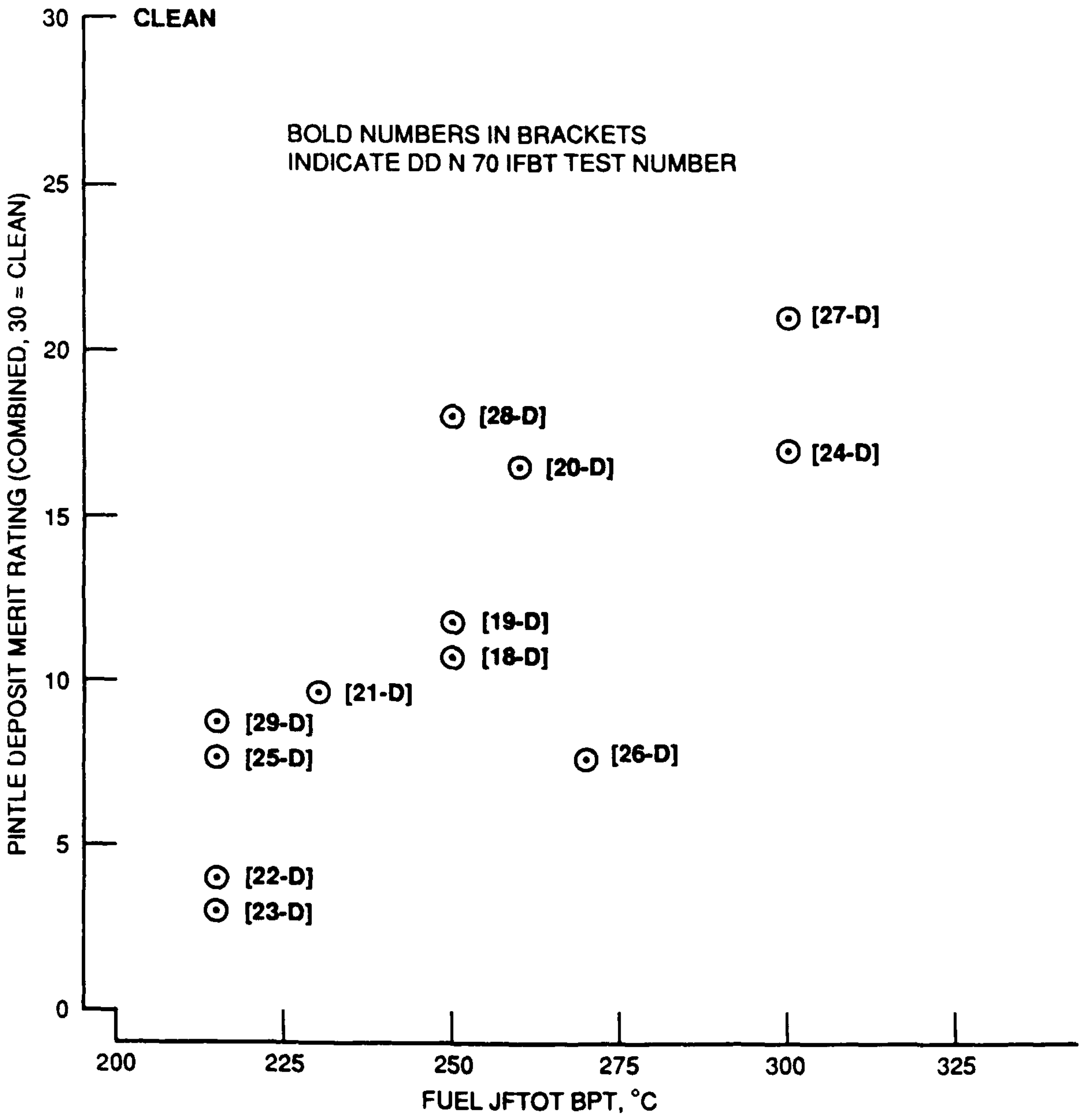


Figure 11. <u>**DD N70 injector pintle merit rating versus fuel JFTOT breakpoint temperature (Code 3 inception temperature) for IFB Test Nos. 18-D to 29-D**</u>

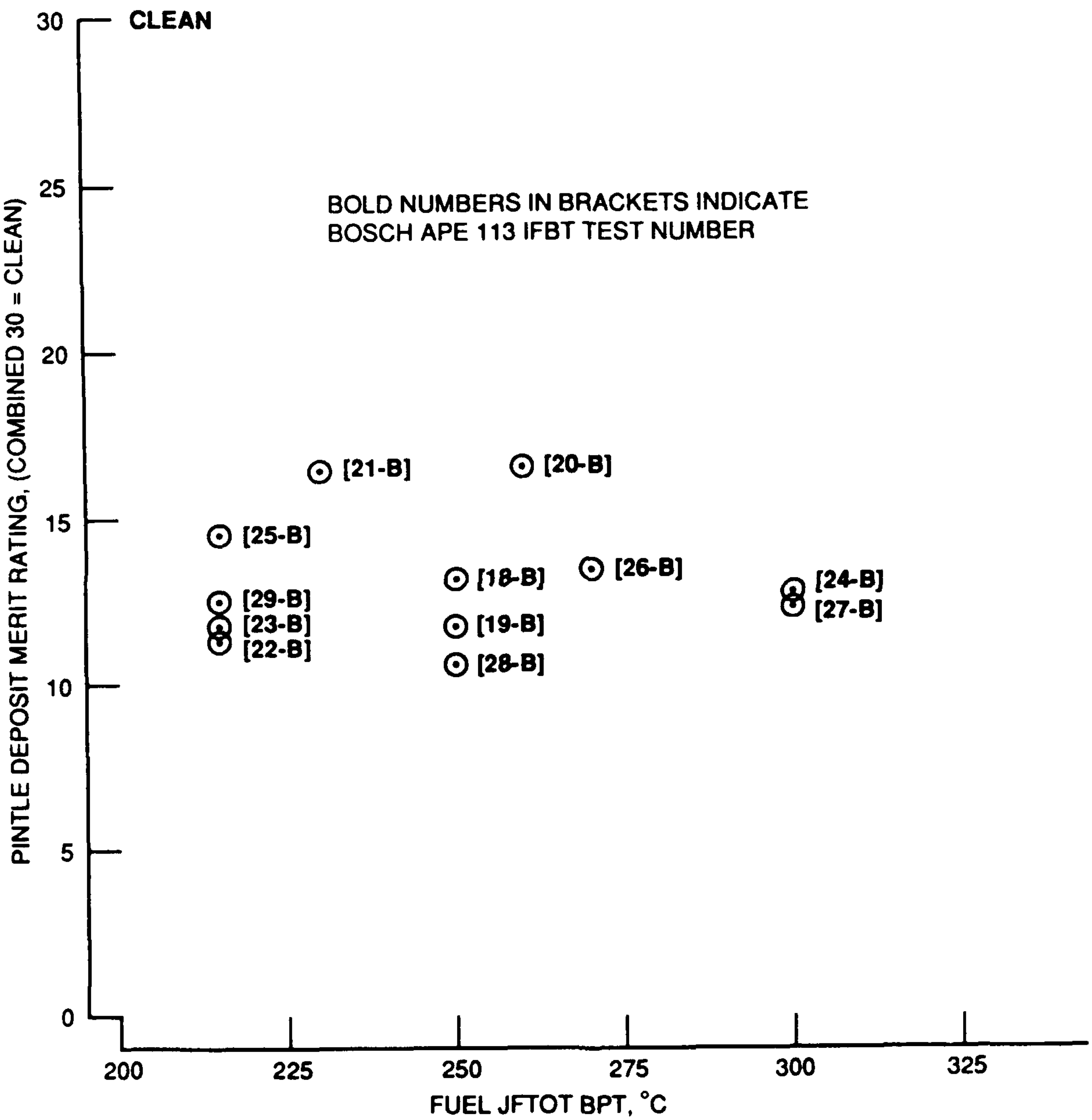
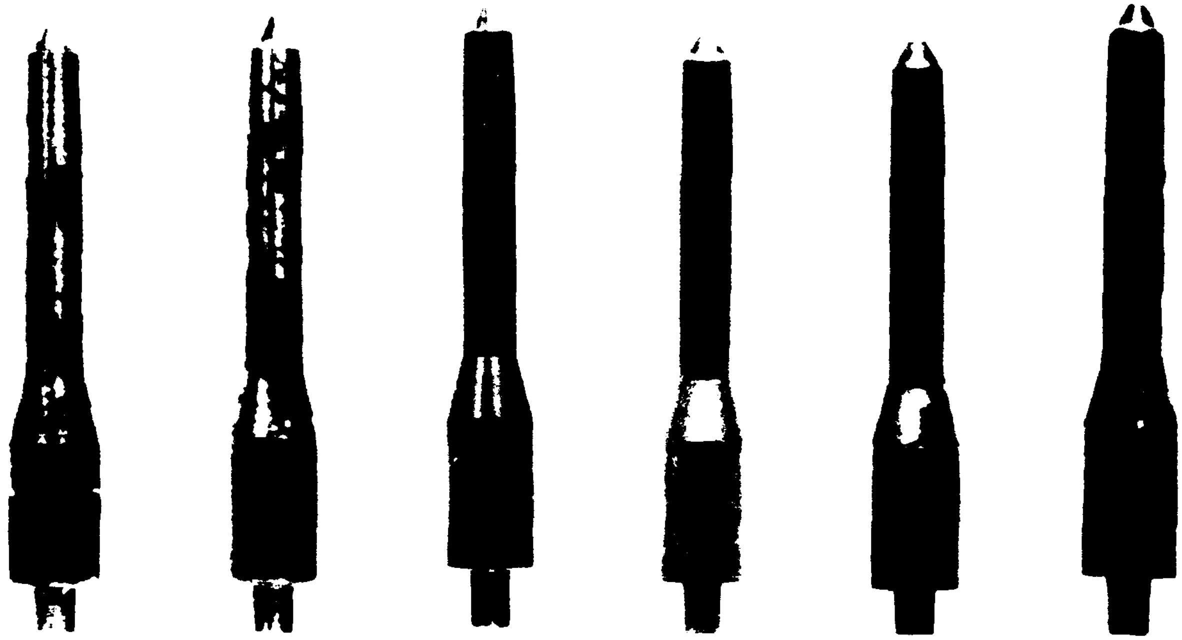
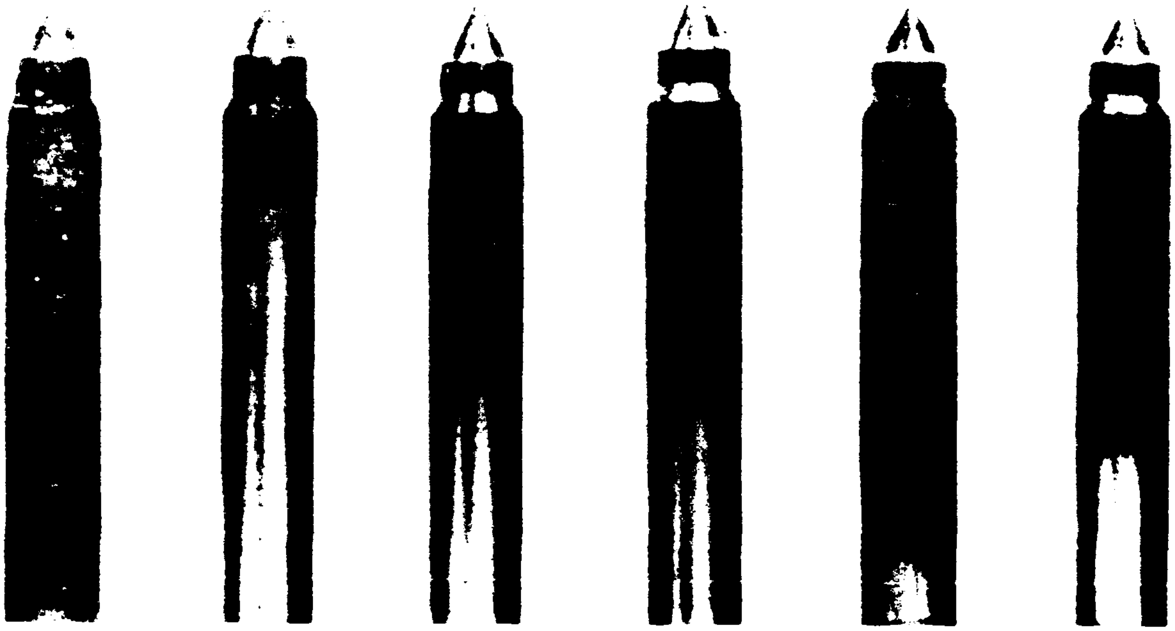


Figure 12. Bosch APE 113 injector pintle merit rating versus fuel JFTOT breakpoint temperature (Code 3 inception temperature) for IFB Test Nos. 18-B to 29-B



16 hr. (600° F)	40 hr.	80 hr.	80 hr.	36.5 hr.	80 hr.
15-D	16-D	26-D	27-D	28-D	29-D
(1.4)	(2.1)	(2.5)	(5.0)	(6.0)	(3.8)



40 hr.	40 hr. (500° F)	80 hr.	80 hr.	80 hr.	40 hr.
15-B	16-B	26-B	27-B	28-B	29-B
(3.3)	(3.2)	(4.0)	(3.4)	(1.5)	(3.5)

Figure 13. Optical microscopic (4X) photographs of selected DD N70 and Bosch APE 113 injector pintles

[Merit rating (10 = clean) of nonrubbing area given in parentheses.]

Nozzle tip heating block temperature was 550°F except for IFBT 15-D and IFBT 16-B (500°F)

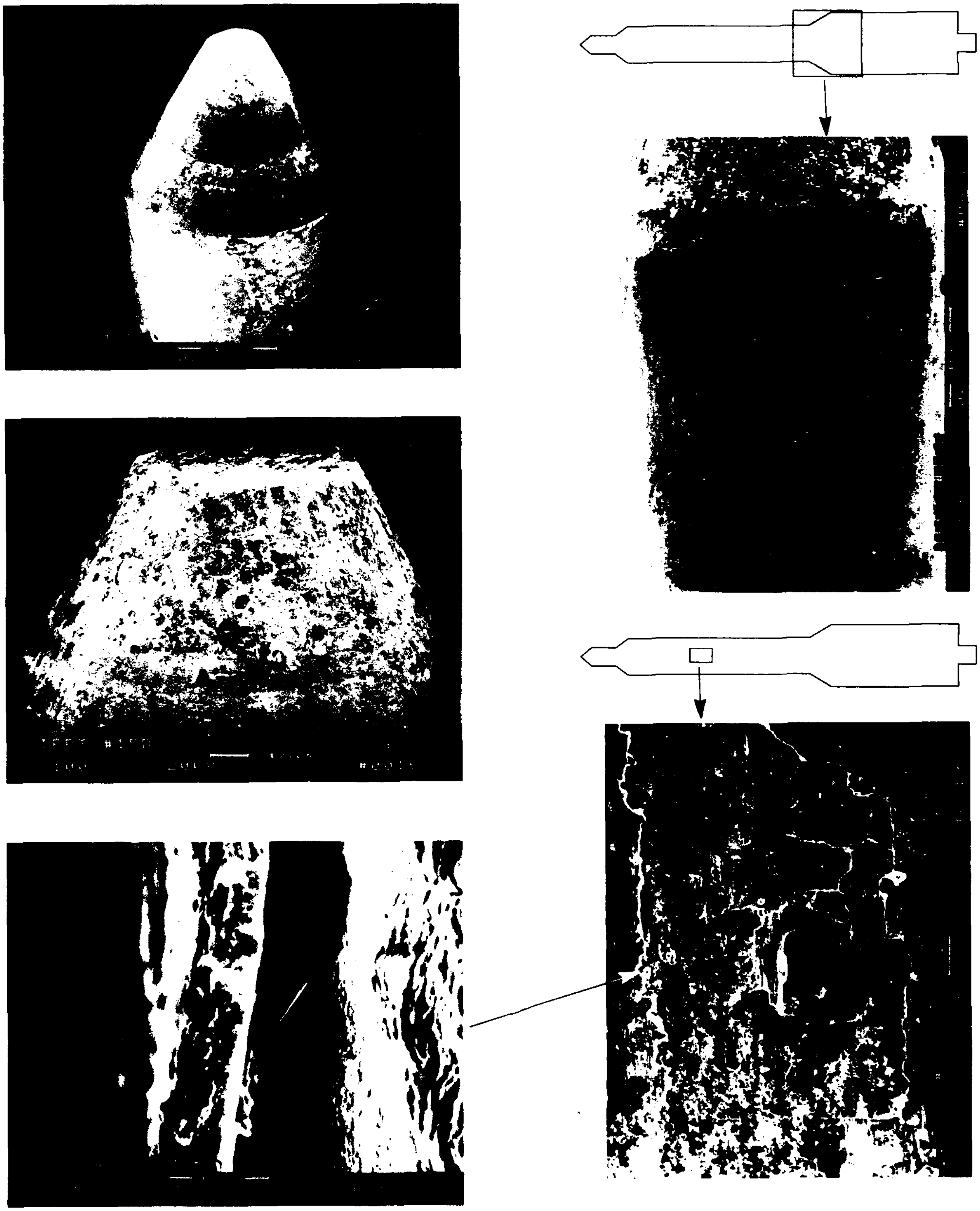


Figure 14. <u>**SEM photographs of IFB Test No. 15-D, DD N70 pintle**</u>

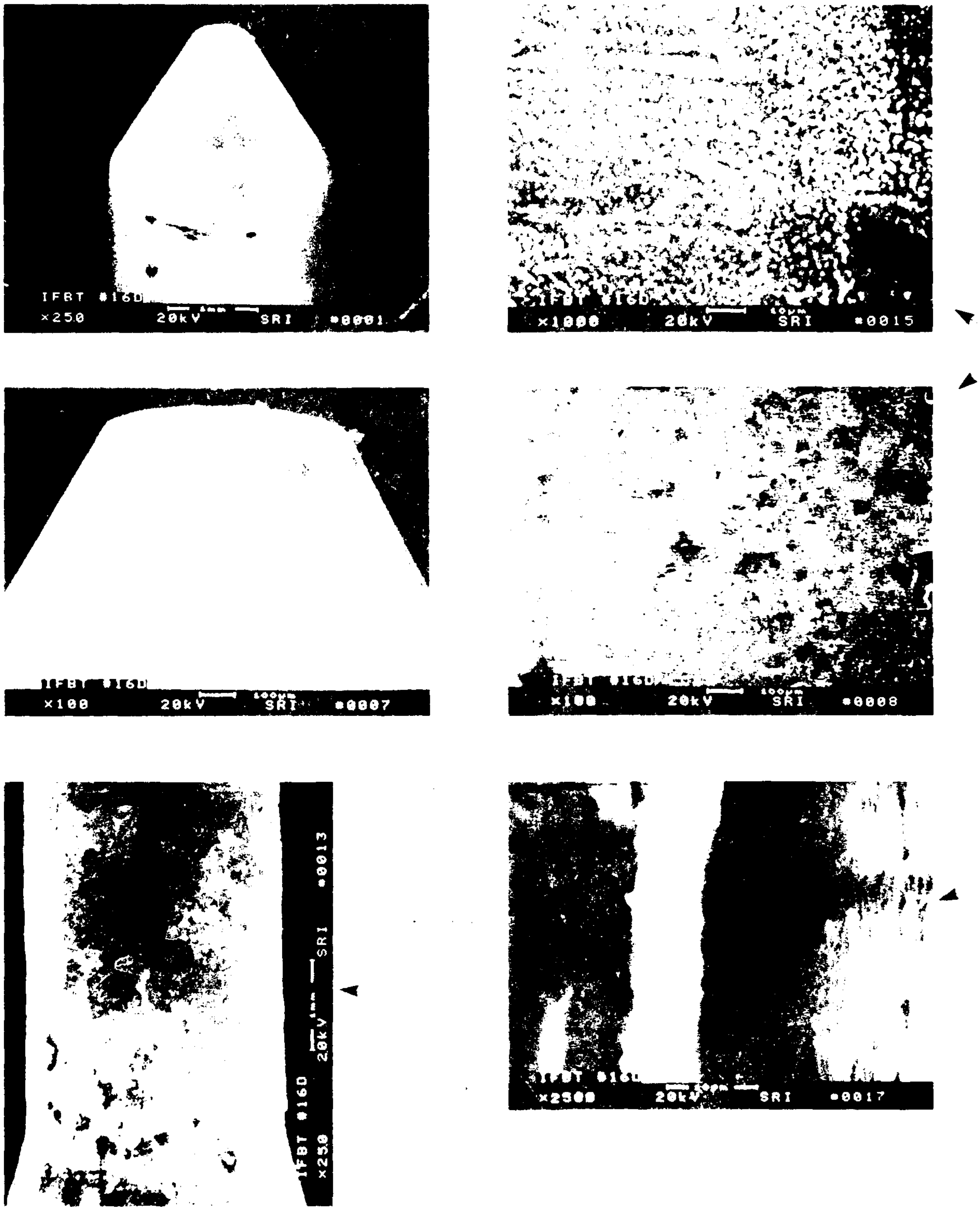


Figure 15. SEM photographs of IFB Test No. 16-D, DD N70 pintle

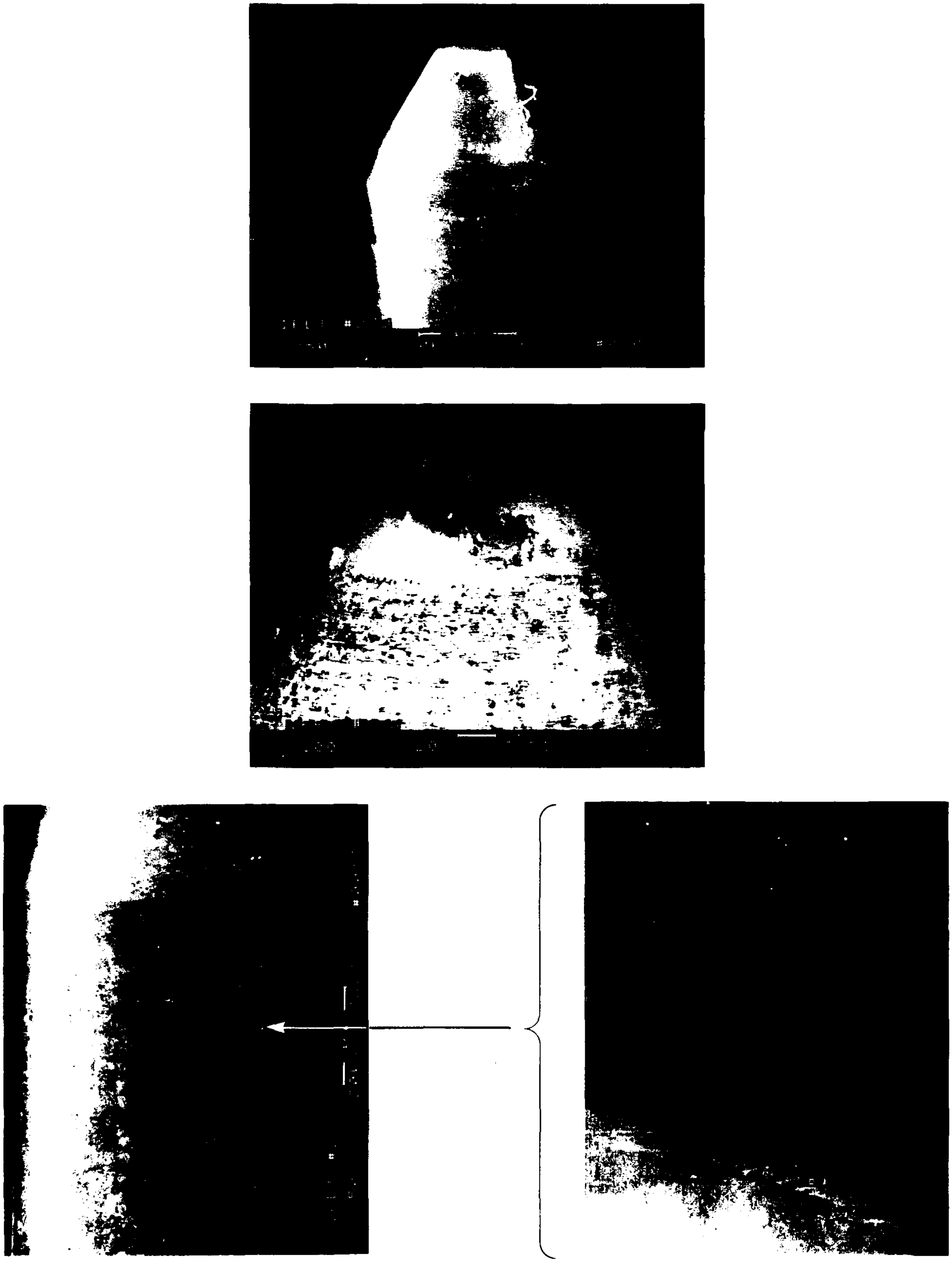


Figure 16. SEM photographs of IFB Test No. 27-D, DD N70 pintle

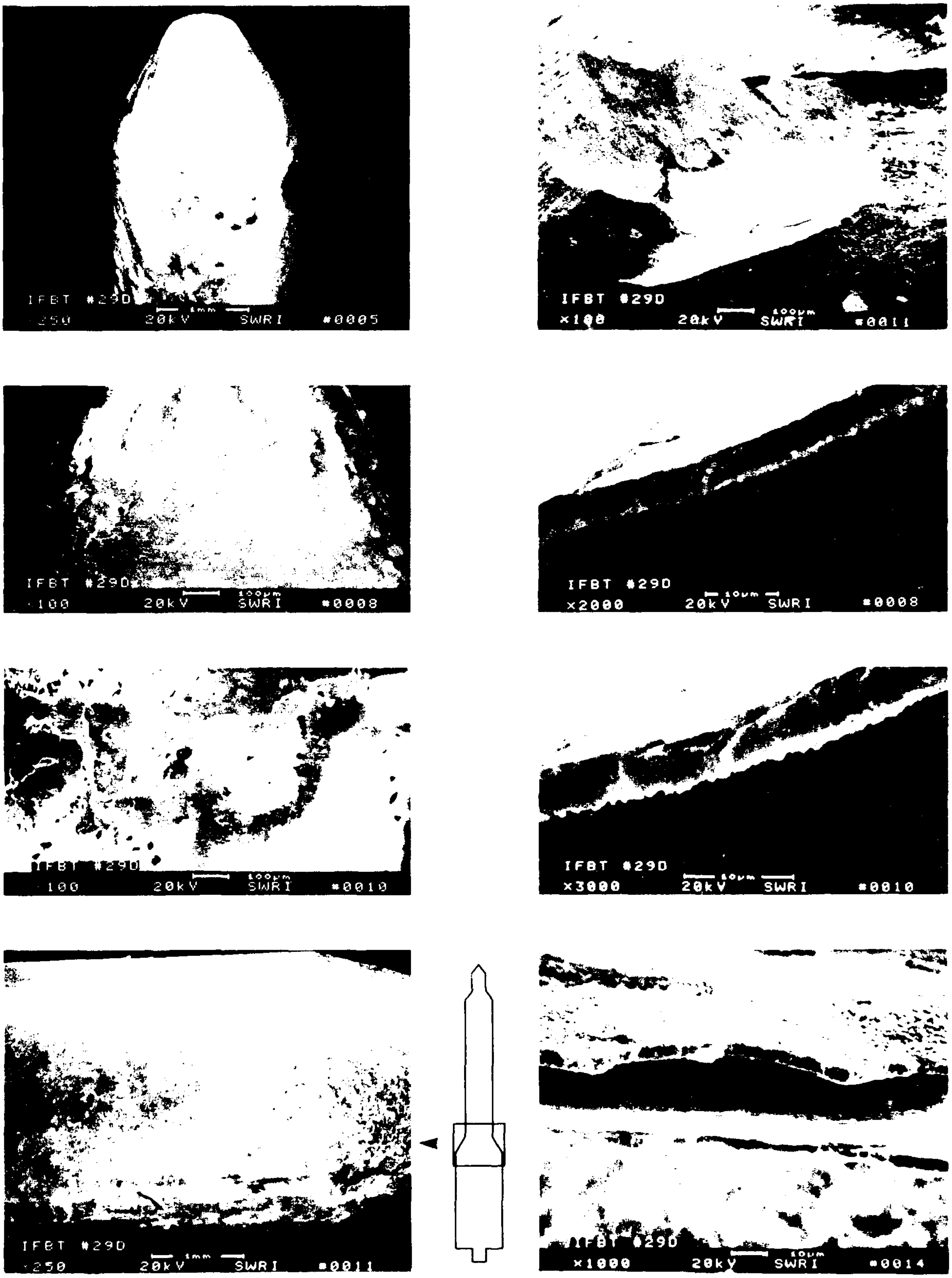


Figure 17. SEM photographs of IFB Test No. 29-D, DD N70 pintle

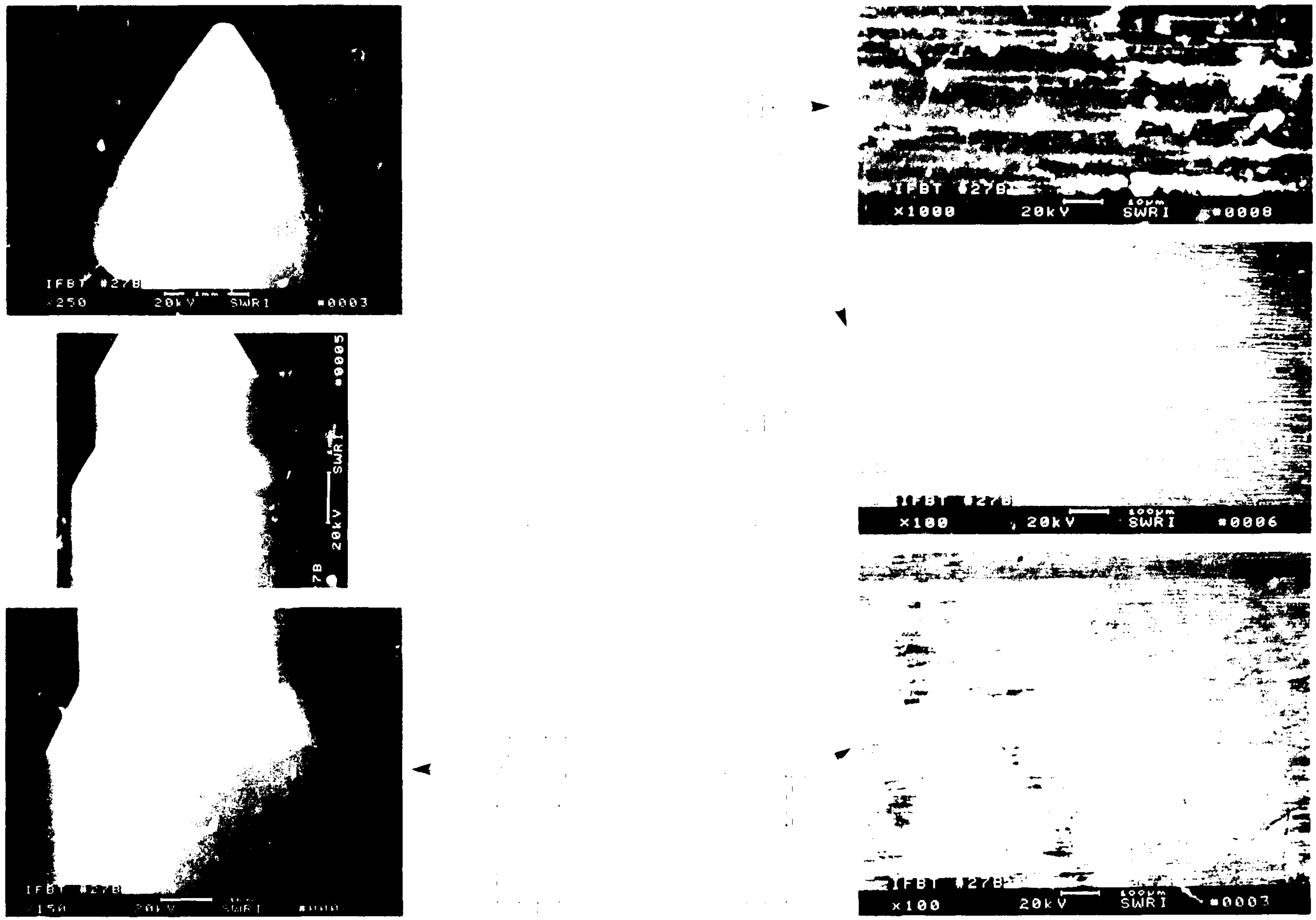


Figure 18. SEM photographs of IFB Test No. 27-B, Bosch APE 113 pintle

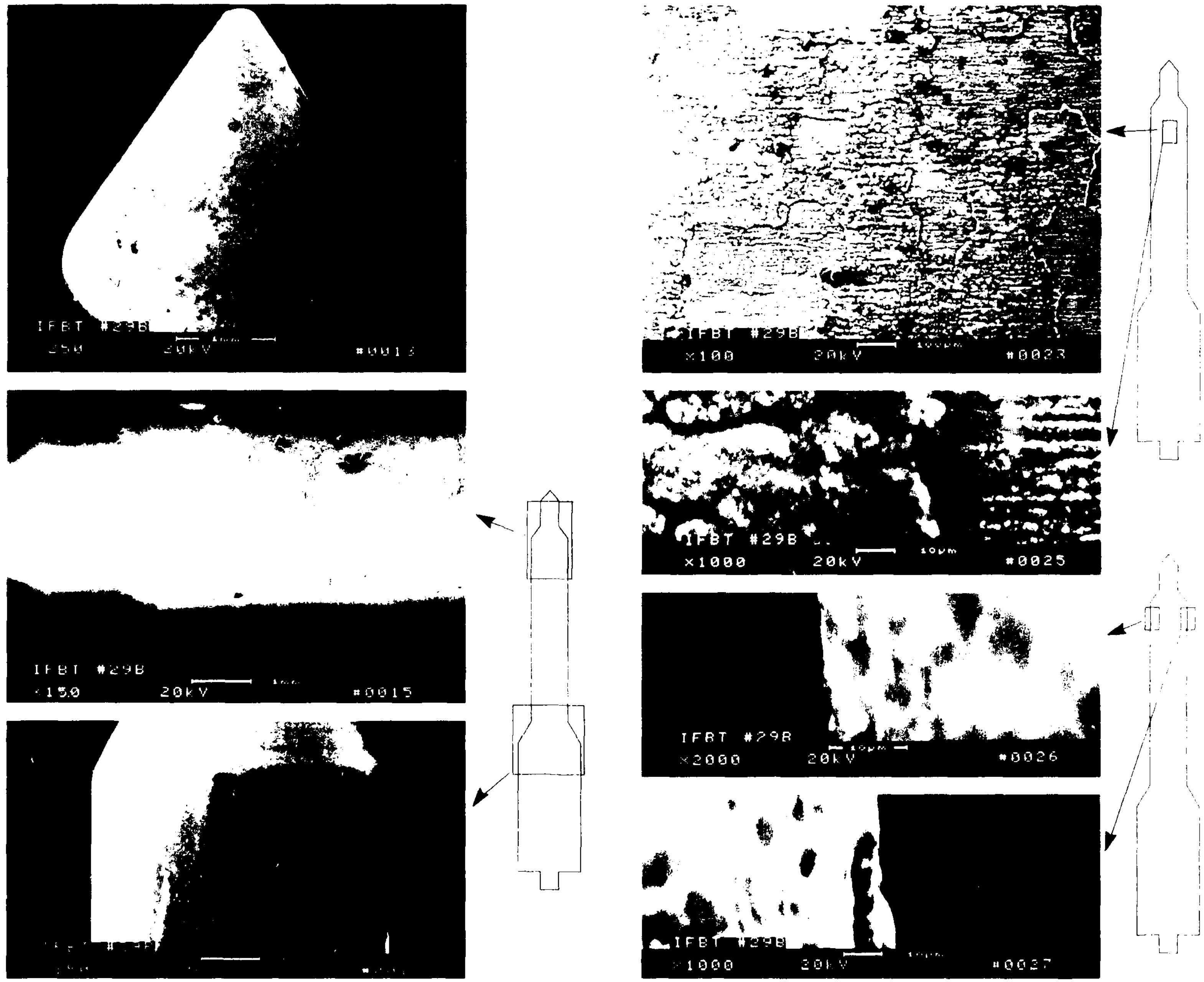


Figure 19. SEM photographs of IFB Test No. 29-B, Bosch APE 113 pintle

thickness in the range of 5 to 7 micrometers. Fig. 14 shows SEM photographs of IFB Test No. 15-D with a DD N70 pintle. This test ran only 16 hours before the pintle froze in the nozzle and had to be cut out. Deposits on the pintle measured 7 to 10 micrometers in thickness. Surface adhesion of the deposits was random, with variable flaking. This degree of deposit formation was not indicated by visual merit ratings or sensed by DMD measurements (indicating that the deposits may be electrically conductive).

Fig. 15 shows SEM photographs of IFB Test No. 16-D, DD N70 pintle (same fuel as in IFB Test No. 15-D, but with a nozzle heater tip temperature of 288°C (550°F) compared to 316°C (600°F) in IFB Test No. 15-D). The deposits measured 3 to 5 micrometers in thickness. SEM photographs (Fig. 16) of IFB Test No. 27-D, DD N70 pintle (fuel was JP-8) showed no deposit scale. SEM photographs (Fig. 17) of IFB Test No. 29-D, DD N70 pintle (80-hour test using 1-percent sulfur fuel without additives) showed an abundance of scaly deposit measuring 5 to 8 micrometers in thickness.

Figs. 18 and 19 are SEM photographs of Bosch APE 113 pintles from IFB Test Nos. 27-B (JP-8 fuel run 80 hours) and 29-B (1-percent sulfur fuel run 40 hours), respectively. Note the lack of scale deposits in Fig. 18 and the abundance of scale deposits (thickness measuring 5 to 8 micrometers) in Fig. 19. Fuel analysis before tests (TABLE C-3 of Appendix C) could support abundance of deposits based on high D 2274 instability, oxygen overpressure instability, and a low JFTOT breakpoint temperature for the 1 percent sulfur fuel relative to both the JP-8 and the R2DF used in the 80-hour cyclic injector fouling tests.

IFBT Nos. 28 and 29 used fuel from two different drums of 1 percent sulfur reference fuel procured in 1986 (TABLE 1). The data in TABLE C-3 (Appendix C) shows the fuel equivalent except for higher particulates and lower thermal stability for fuel Code 19444. Extensive JFTOT data were developed in TABLE C-5 (Appendix C) to differentiate between these two drums of fuel as well as the R2DF fuel (for IFBT Runs 26-B and 26-D) and the JP-8 fuel (for IFBT Runs 27-B and 27-D).

A later batch of R2DF (Code 18987, procured in August 1989) was used for the 80-hour IFB Test Nos. 26-B and 26-D. This fuel gave considerably less deposits than the 1 percent sulfur fuel used in IFB Test Nos. 28 and 29 (each of which used a different drum of fuel). While the normal JFTOT test time is 2.5 hours, with a flow rate of 3 mL/minute, a number of other test conditions (as shown in TABLE C-5 of Appendix C) were used for these three fuels (coded 18987, 15542, and 19444) and the JP-8 (coded 19393) in an effort to find conditions that would differentiate between fuels. Use of the 4X tube holder (for the 1 percent sulfur fuels) increases the fuel residence time in the heater tube holder, making for a more severe test, which showed sample Code 19444 to be somewhat less stable; however, when the flow rate of 1.0 mL/minute was used, both (drums of 1 percent sulfur) fuels rated essentially equal. Variations in test time (including three consecutive 2.5-hour tests using the heater tubes) did not show significant JFTOT deposit tendency differences between the R2DF (Code 18987) or the 1 percent sulfur fuel (Code 19444).

VI. CONCLUSIONS AND RECOMMENDATIONS

A. Conclusions

The following conclusions were formed as a result of this study:

- 40-hour cyclic IFB tests employing both Bosch APE 113 and Detroit Diesel (DD) N70 injectors are viable procedures for evaluating fuel effects on injector fouling. Cyclic operation appears to be superior to steady-state operation. Also, 80-hour cyclic tests are more discriminating than 40-hour cyclic testing (especially when using the Bosch APE 113 injector bench test, which is less severe than the DD IFBT, possibly due to the lack of fuel recycling that occurs in the Detroit Diesel injector bench test rig).

- JFTOT tests of fuels provide directional information on fuel thermal stability-related deposits and filter plugging; however, they show limited good correlation with IFBT DD N70 injector deposit ratings and none with IFBT Bosch APE 113 injector ratings.

The limited good correlations for the IFBT DD N70 pintle deposits lies somewhat in the merit rating system not being quantitative or relating to deposit thickness.

- High-sulfur (from di-*tert*-butyl disulfide) fuel readily causes sticking of Detroit Diesel injectors. The 1-percent sulfur fuel (without additive) was most effective in causing pintle deposits, but these deposits were best seen as deposit scale on the pintle observed by optical microscope and SEM.

- Injector sticking is an important mode of injector fouling and is thought to be related to insoluble formation from fuel unstable components. The close tolerance rubbing portion of the pintle in contact with the nozzle body is thought to act as a fine filter, causing deposit buildup and eventually causing the pintle to stick. The injector nozzle bodies were not directly inspected (other than for airflow restriction through the nozzle tip holes), because of inaccessibility to the inside surface of the nozzle bodies. However, it is likely that as much or more deposits are formed on the inside of the nozzle body as are found on the pintle for any one given test, when one considers that heating is accomplished using a nozzle tip heater block.

- Deposit rating techniques such as the CRC brown lacquer merit scale did not provide definitive deposit data for injector pintles when deposits were compared by microscope and SEM techniques.

- This methodology appears attractive for investigating fuels containing known thermally unstable components.

B. Recommendations

It is recommended that the DD N70 injector fouling bench test methodology and quantitative JFTOT be utilized in high-temperature fuel studies such as unstable fuel pretreatment evaluation for advanced integrated propulsion system engines requiring thermally stable fuel. Quantitative techniques are needed for rating deposit levels on injector pintles. Both optical microscopic and

SEM methods of evaluating deposits should be utilized and improved as quantitative deposit rating methods. Nozzle pintle sticking tendencies should also be quantified.

VII. REFERENCES

1. MacDonald, J.W. and Jones, R.T., "Predictive Type Tests for Storage Stability and Compatibility of Diesel Fuels," American Society for Testing and Materials Special Technical Publication No. 244, pp. 5-14, 1916 Race St., Philadelphia, PA, February 1959.

2. LePera, M.E., "Thermal-Oxidative Stability of Automotive Diesel Fuels," CCL Report No. 321, Interim Report, Coating and Chemical Laboratory, Aberdeen Proving Ground, MD, February 1973.

3. Final Letter Report of Research Test of Diesel Fuel Injector Fouling Tendencies, RDT&E Report number not available, USATECOM No. 7-EG-535-000-003, 30 October 1969.

4. Letter Report AMXSH-TP From Sharpe Army Depot, dated 7 November 1967, Subject: Diesel Fuel Contamination at Camp Pendleton.

5. "Interim Progress Report on Whiteman AFB Missile Site Fuels," U.S. Army Fuels and Lubricants Research Laboratory, Southwest Research Institute, San Antonio, TX, 6 February 1968.

6. Stavinoha, L.L., Westbrook, S.R., and Brinkman, D.W., "Accelerated Stability Test Techniques for Diesel Fuels," Report No. DOE/B/10043-12, U.S. Department of Energy, October 1980.

7. Stavinoha, L.L. and Westbrook S.R., "Accelerated Stability Test Techniques for Middle Distillate Fuels," **Distillate Fuel Stability and Cleanliness**, American Society for Testing and Materials Special Technical Publication No. 751, pp. 3-21, 1916 Race St., Philadelphia, PA, 1981.

8. Stavinoha, L.L. and LePera, M.E. "A Review of Diesel Fuel Deterioration and Related Problems," Interim Report AFLRL No. 88 (AD A043566), prepared by U.S. Army Fuels and Lubricants Research Laboratory, Southwest Research Institute, San Antonio, TX, May 1977.

9. Stavinoha, L.L., Westbrook, S.R., and LePera, M.E., "Army Needs for Diesel Fuel Stability and Cleanliness," **Distillate Fuel Stability and Cleanliness**, American Society for Testing and Materials Special Technical Publication No. 751, pp. 103-125, 1916 Race St., Philadelphia, PA, 1981.

10. Burman, P.G and DeLuca, F., <u>Fuel Injection and Controls for Internal Combustion Engines</u>, pp. 110-111, copyright 1962.

11. Olsen, R.E., Ingham, M.C., and Parsons, G.M., "A Fuel Additive Concentrate for Removal of Injector Deposits in Light-Duty Diesels," SAE Paper No. 841349.

12. Fortnagel, M. and Herrbrich, B., "Effects of Fuel Stability Upon Injection Nozzle Deposit Formation in Road Tested Diesel Engines," 49th Midyear Refining Meeting, American Petroleum Institute Order No. 820-00012, May 1984.

13. Halsall, R., "Effects of An Unstable Diesel Fuel on Injector Coking and Vehicle Performance," Proceedings of 2nd International Conference on Long-Term Storage Stabilities of Liquid Fuels," published by Southwest Research Institute, San Antonio, TX, October 1986.

14. Gallant, T.R., Cusano, C.M., Gray, J.T., and Strete, N.M., "Cummins L10 Injector Depositing Test to Evaluate Diesel Fuel Quality," SAE Paper No. 912331.

15. Korus, R.A., Jo, J., and Petterson, C.L., "A Rapid Engine Test to Measure Injector Fouling in Diesel Engines Using Vegetable Oil Fuels," JOACS, Vol. 62, No. 11, pp. 1563-1564, November 1985.

16. Gardner, T.P., "Investigation of the Effects of Engine Design Parameters on Diesel Combustion and Emissions Using Taguchi Methods," SAE Paper No. 920116.

17. Stavinoha, L.L., Barbee, J.G., and Yost, D.M., "Thermal Oxidative Stability of Diesel Fuels," Interim Report BFLRF No. 205 (AD A173850), prepared by Belvoir Fuels and Lubricants Research Facility, Southwest Research Institute, San Antonio, TX, February 1986.

18. Stavinoha, L.L., Yost, D.M., and Barbee, J.G., "Thermal Stability of Diesel Fuels," Proceedings of 2nd International Conference on Long-Term Storage Stabilities of Liquid Fuels, published by Southwest Research Institute, San Antonio, TX, 1986.

19. Stavinoha, L.L., Barbee, J.G., and Buckingham, J.P., "Thermal Stability Deposit Measuring Device," Proceedings of 2nd International Conference on Long-Term Storage Stabilities of Liquid Fuels, published by Southwest Research Institute, San Antonio, TX, 1986.

20. Morris, R.E. and Hazlett, R.N., "Methods for Quantifying JFTOT Heater Tube Deposits Produced From Jet Fuels," Energy and Fuels, Vol. 3, pp. 262-267, 1989.

21. Taylor, W.F., "High Thermal Stability Liquid Hydrocarbon and Methods for Producing Them," U.S. Patent No. 4,330,302, May 18, 1982.

22. Westbrook, S.R., Stavinoha, L.L., and Present, D.L., "Studies of Diesel Fuel Insolubles Formation and Fuel Stabilizer Additives," Interim Report BFLRF No. 255 (AD A202297), prepared by Belvoir Fuels and Lubricants Research Facility (SwRI), Southwest Research Institute, San Antonio, TX, August 1988.

23. "Road Vehicles — Calibrating Nozzle, Delay Pintle Type," International Standards Organization, ISO 4010 - 1977E.

24. Naegeli, D.W. and Marbach, H.W., Jr., "Role of Sulfur Oxides in Wear and Deposit Formation in Army Diesel Engines," Interim Report BFLRF No. 248 (AD A206054), prepared by Belvoir Fuels and Lubricants Research Facility, Southwest Research Institute, San Antonio, TX, December 1988.

LIST OF ABBREVIATIONS

ASME	American S... y of Mechanical Engineers
ASTM	American Society for Testing and Materials
Belvoir RDE Center	U.S. Army Belvoir Research, Department and Engineering Center
BFLRF	Belvoir Fuels and Lubricants Research Facility
BPT	Breakpoint Temperature
CI	Compression Ignition
CLR-D	Coordinating Lubricant Research-Diesel
CRC	Coordinating Research Council
DD	Detroit Diesel
DF-2	Diesel Fuel No. 2
DMD	Deposit Measuring Device
E&S	Engineering and Services
gal.	Gallon
GMC	General Motors Corporation
IFB	Injector Fouling Bench
IFBT	Injector Fouling Bench Test
ISO	International Standardization Organization
JFTOT	Jet Fuel Thermal Oxidation Tester
lb	Pound
LCGO	Light Coker Gas Oil
hr	Hour
MFO	Marine Fuel Oil
MTD	Materials Test Directorate
ND	Not Determined
NES	Not Enough Sample
NT	Not Tested
ppb	Parts per billion
R2DF	Reference No. 2 Diesel Fuel
REC	Recycled Fuel
Ref. No. 2	Reference No. 2
rpm	Revolutions per minute
S	Sulfur
SEM	Scanning Electron Microscopy
STD	Standard
STP	Special Technical Publication
SwRI	Southwest Research Institute
TBDS	di-*tert*-butyl disulfide
TBHP	*tert*-butyl hydroperoxide
TDR	Tube Deposit Rating

APPENDIX A

Detroit Diesel N70 Injector Fouling Bench Test (IFBT) Cyclic Procedure

DETROIT DIESEL N70 INJECTOR FOULING BENCH TEST (IFBT) CYCLIC PROCEDURE

1. Preparation for Test

Prior to the test, the injector baseline performance is documented. The injector is examined for injection pressure and leakdown on the Pop-n-Fixture® machine (Attachment A). Additional tests include a nozzle airflow check (Attachment B), fuel flow test (Attachment C), and a TDR spun rating for baseline data of a clean pintle/plunger. This data must be recorded and maintained throughout the test. The test fuel undergoes a battery of tests listed in Table 1.

TABLE 1. FUEL TESTS

Color, ASTM D 1500
JFTOT, ASTM D 3241, Breakpoint
Particulate Contamination, ASTM D 2276
Accelerated Stability, ASTM D 2274
Steam Jet Gum, ASTM D 381
Accelerated Stability, 150°C Test
Carbon Residue, 10% Bottoms, D 524

2. Procedure

Procure 13 gallons of the test fuel. One gallon is sent to the laboratory for testing, and 12 gallons are used for the injector rig test.

The Detroit Diesel Injector Rig controls are listed in Attachment D.

The injector rig is operated in the **automatic cyclic mode,** which automatically turns off the injector rig after 15 minutes. The injector rig remains off for another 15 minutes and then turns back on automatically. This procedure is repeated throughout the test. The injector is operated at the condition described in Table 2.

Record test number of Detroit Diesel N70 Injector Fouling Bench Test in a log book to be kept by the injector rig. Use the letter D after test number to indicate the injector rig used is the Detroit Diesel. Table 3 lists the information to be recorded in the IFBT log book. Figure 1 illustrates the daily log book requirements.

TABLE 2. DETROIT DIESEL N70 IFBT OPERATING CONDITIONS FOR 40 HOURS (8 PER DAY)

	On 15 Minutes	Off 15 Minutes
Speed, rpm	1000	0
Fuel Flow, gal/hr	0.5	0
Fuel Spray Temp, ^oC (^oF)	260 (500)*	Record
Temperature of Nozzle Tip Heating Block, ^oC (^oF)	288 (550)	Record
Fuel Reservoir Temp, ^oC (^oF)	79 (175)	79 (175)

* Target temperature.

TABLE 3. LOG BOOK INFORMATION

Test number

Test fuel by AL-Code

Test fuel description

Date test starts

Date test ends

Total hours of test

First two hours; then approximately each 2 hours for an on-and-off cycle record as follows:

- Ambient temperature
- Humidity
- Test hour
- Speed, rpm
- Time of day
- Barometric pressure
- Wet bulb temperature
- Spray temperature
- Nozzle tip heating block temperature
- Fuel reservoir temperature
- Fuel flow

DETROIT DIESEL N70 INJECTOR FOULING BENCH TEST

Test No.__________ Date __________ Technician __________ Page No.______

Test Fuel AL–Code ____________________

Test Fuel Description ______________________________________

Date Test Starts ______________ Date Test Ends ______________ Total Hours of Test ______

Test Hour								
Time of Day								
Barometric Pressure, in Hg								
Ambient Temperature, Deg. F								
Wet Bulb, Deg. F								
Relative Humidity. %								
Speed, RPM								
Fuel Reservoir Temperature, Deg. F								
Spray Temperature, Deg. F								
Nozzle Tip Heating Block Temperature, Deg. F								
Fuel Flow, mL/MIN (31.5)								

FIGURE 1. DETROIT DIESEL N70 INJECTOR FOULING BENCH TEST LOG SHEET

The fuel lines in the injector rig should be stainless steel, and the fuel reservoir must be made of stainless steel. Copper or brass must not be allowed to come in contact with the test fuel at any time. The reservoir must be clean and able to maintain a fuel temperature of 79°C (175°F) during the daily test and 50°C (122°F) during the time rig is shutdown between daily test runs.

A digital readout thermometer is adequate if personnel are available to check the temperature periodically during the test run.

The injector test is run at maximum temperature for eight hours a day, as listed in Table 4, to enable a 40-hour test to be completed within one week (5 successive workdays). To allow for cool-down time, all heaters, except the fuel reservoir, will be turned off during the last 15 minutes of the eighth hour each day.

At the end of the test, save approximately one gallon of test fuel from the fuel reservoir for further laboratory analyses. Table 5 contains the end-of-test cleanup procedure for the injector rig. The test fuel undergoes a series of tests listed in Table 6.

Post-test performance evaluations include the evaluations of the injection pressure and leakdown time (Attachment A), plus the airflow test for the determination of nozzle hole plugging (Attachment B). The airflow evaluation is a modification of the ISO 4010-1977(E) standard.

Also, following the completion of the test, the pintle/plungers are rated for deposition by the methods listed in Table 7 and compared to their respective before-test measurements. Results are then listed in the work sheets as illustrated in Figure 2. Pintle should always remain wetted by Jet-A except during evaluations (heptane washing is permissible before each evaluation).

TABLE 4. DETROIT DIESEL DAILY OPERATION

1. At 7:30, turn fuel barrel temperature controller up to 175°F.

2. Add any make-up oil (REO 191, AL-6211-L) to rocker arm oiling system and start system dripping slowly.

3. At 8:00 AM, start test; turn on breaker to rig, main power light will come on, turn clock-manual switch to clock and turn nozzle injector controller up to reach test temperature. First 15 minutes of cycle is heat soak.

4. Adjust rpm to 1000.

5. Adjust return pressure to 30 psi.

6. Check fuel flow rate - place graduated cylinder under fuel time valve. Open valve and collect 20 mL fuel. When fuel level reaches 20 mL, mark, start timer and time flow for 1 minute. Close valve. Let collected fuel cool and read volume collected (0.5 gal/hr = 31.5 mL/min). Adjust flow as needed.

7. Fill in the necessary log book information.

8. Check fuel flow rate every hour.

9. Adjust rpm, return pressure, fuel flow, and temperature controllers as required.

10. During the last 15 minutes of run cycle, turn off nozzle controller and turn down fuel barrel controller to 122°F; stop at 8 hours (4:00 PM).

11. Stop recorder, turn off right-side breaker and turn off oilers. Fuel barrel stays on at 122°F overnight.

Note: **At the end of the 40-hour test, a 1-gallon sample of test fuel is taken from the fuel reservoir, properly labeled and taken to chem lab for tests.**

TABLE 5. DETROIT DIESEL INJECTOR RIG END-OF-TEST CLEANUP PROCEDURE

1. When the system has cooled to ambient temperature, remove the fuel filter element and save in a sealed can.
2. Clean filter housing and reinstall without a filter element.
3. Disconnect the fuel lines at the injector and install jumper adaptor to bypass the injector.
4. Disconnect both fuel lines from the lid of the fuel drum and remove the lid. Remove both lines attached to underside of lid and reconnect to pump inlet and return lines. The lid is not used during cleanup. Pump any remaining fuel to waste container.
5. Wash down the inside walls of fuel drum with approximately 1000 mL of iso-octane.
6. Open the drain valve and using electric fuel pump, drain the washings to slop container. Stop pump.
7. Close the drain valve and add approximately 2000 mL of fresh iso-octane to fuel drum.
8. Place the fuel bypass return line in slop can--pump the washings through the system and into waste can. Note: **The return pressure valve might have to be adjusted to get more flow at this point.**
9. Stop the pump and drain the iso-octane from the fuel filter housing.
10. Wash down the inside walls of fuel drum with approximately 1000 mL of TAM.
11. Repeat Step Nos. 6 through 9 using TAM as the wash.
12. Pour approximately 2000 mL of neat Cat 1H or the next test fuel and circulate through the system into waste container to remove any solvents remaining in the system.
13. When the system is pumped dry, install new fuel filter element for the next test.

TABLE 6. AFTER IFBT TEST FUEL ANALYSIS

Color, ASTM D 1500

Visual, ASTM D 4176

JFTOT, ASTM D 3241, Breakpoint Temperature

Particulate Contamination, ASTM D 2276

Steam Jet Gum, ASTM D 381

Total Acid Number, ASTM D 664

Carbon Residue, 10% Bottoms, ASTM D 524

TABLE 7. IFBT DEPOSITION RATING*

Visual CRC lacquer demerit scale

JFTOT visual rating scale

TDR spun rating

Dielectric breakdown by Deposit Measuring Device (DMD)

Stereooptical examination plus micro DMD

* **NOTE:** Prior to testing, rinse the pintle with heptane to remove residual fuel and air dry. After each test, rewet the pintle with Jet-A fuel before replacing in its respective case.

DETROIT DIESEL N70 UNIT INJECTOR
IFBT INSPECTION WORKSHEET

DATE ____________ TEST NO. ____________ TEST HOURS ____________ INSPECTOR ____________

FUEL AL– NO. AND DESCRIPTION ________________________________

TEST	TYP./REF.	BEFORE	AFTER
INJECTION PRESSURE PSI	135		
LEAKDOWN dP;15 SEC.	0		
SPRAY PATTERN	GOOD BAD		
AIR FLOW CC/MIN.	REPORT		
FUEL FLOW ML/100 STROKES	60–75		

PINTLE MERIT RATING		
RUBBING		
AREA	RATE	MERIT
	TOTAL	
NON–RUBBING		
AREA	RATE	MERIT
	TOTAL	
TIP		
AREA	RATE	MERIT
	TOTAL	

TDR SPUN RATING

STATION	BEFORE	AFTER	CALC. VALUE

DIELECTRIC BREAKDOWN

STATION	0	90	180	270	AVG.
					CSL

FIGURE 2. DETROIT DIESEL N70 UNIT INJECTOR IFBT INSPECTION WORK SHEET

Attachment A
PART I

Pop-N-Fixture®
J23010
Kent-Moore
Tool Division
29784 Little Mack
Roseville, Michigan 48066

SETUP PROCEDURE

1. Place levers (1) and (2) in rear position.
2. Install proper adaptors and lead injector into position.
3. Open thru-flow valve (over injector fuel fitting).
4. Move valve (3) to clamp position--up.
5. Operate pump lever (4) carefully until injector is clamped.
   Caution: Excessive clamping force will damage the tester.
6. Move valve (3) to test position--down.

SPRAY PATTERN AND TIP TEST

1. Move lever (2) to "spray and tip test position"--forward.
2. Open thru-flow valve.
   Caution: Closed valve will damage left gauge.
3. Operate pump lever (4) and observe spray pattern.
4. Operate pump lever (4) slowly, and observe valve opening pressure reference value (right gauge).

Calibration Fluid (AL-12688-L)
Viscor 1487

Viscosity Oil Co.
2.58 cSt at 100°F
0.823 S.G. at 60°F

Attachment A
PART II

HIGH-PRESSURE TEST

1. Move lever (2) to high pressure--rear position.

2. For crown valve injector, rotate lever (1) to crown valve high-pressure test--forward. For needle valve injector, leave in all other tests--rear.

3. Close thru-flow valve.

4. Operate pump lever (4) slowly until high-pressure gauge reads 1600 to 2000 psi and inspect for leaks.

LEAK DOWN TEST

1. Place levers (1) and (2) in rear position.

2. Open thru-flow valve, close, then pump to 500 psi (approximately).

3. Move valve (3) to clamp position--up.

4. Time pressure drop from 450 to 240 psi (redlines).

UNCLAMPING

1. Open thru-flow valve to release pressure.

2. Move valve (5) to unclamp position--down.

Attachment B

AIRFLOW TESTER PROCEDURE

1. Remove the Bell jar from the tester and lay on its side to keep the rubber gasket clean.

2. Place the "O" ring on the spray assembly and install it in the base of the tester.

3. Attach the adaptor to the pintle stem and tighten the set screw. The adaptor should not prevent the pintle from closing completely.

4. Remove the pintle from the spray assembly.

5. Attach the micrometer to the spray assembly adaptor plate (the circular grooved side of plate faces down) and semitight the nut.

6. Attach the adaptor plate and micrometer to the tester and tighten the screws. The "O" ring on the spray assembly must make a good seal.

7. Swing the micrometer to the side to provide access to the spray assembly. Slide the spring on the pintle and insert pintle into spray assembly. The pintle should move down and spring up freely.

8. While holding pintle in down position, swing the micrometer in place directly over the pintle adaptor and tighten the holding nut on the micrometer.

9. Attach the drive belt and install the Bell jar.

10. Close the inlet valve on the flow meter, have the pintle in the up position and open the vacuum valve. Pull as much vacuum as the system will pull (30 in.) and hold for approximately 10 min. to assure a good seal.

11. Close the vacuum valve and open the intake valve. When pressure returns to zero, close the intake valve.

Attachment B (Cont'd)

12. Put the pintle in the closed position (down) and open the vacuum valve. When the gauge reads 30 in., open the intake valve all the way. There should be no indicated airflow at this point.

13. Slowly raise the pintle using the micrometer in small increments (0.005 to 0.010 in.) and record airflow versus micrometer setting. The maximum airflow is reached when the pintle is all the way up. Convert flow meter reading to cc/min.

14. Close the vacuum valve and open the intake valve. When pressure returns to zero, remove the Bell jar.

Attachment C

FUEL FLOW TESTER FOR DETROIT DIESEL 1000 STROKES

1. Install injector in tester and tighten hand-wheel. Push rack setting on the injector all the way in (wide-open position).

2. Turn on power switch.

3. Reset counter to 1000 strokes and push red start button. When tester stops running after pumping 1000 strokes, empty calibration fluid from graduated cylinder and repeat step 3. This is necessary to purge all air from the system prior to testing injector.

4. Do not reset to 1000! Hold red button in and pump until fluid rises to the zero mL mark on graduated cylinder. Release red button. Reset counter to 1000 strokes and push red start button. When tester stops pumping, record volume collected and empty cylinder.

5. Repeat step No. 4 two times. Three fuel flow tests are required.

6. After third test, empty cylinder and turn power off.

Calibration Fluid used is: AL-12688-L
Viscor 1487

Attachment D

DETROIT DIESEL RIG CONTROLS

1. Power is supplied by two breakers at the rear of test rig. The breaker on the left powers the two wall-mounted temperature controllers. The breaker on the right powers the test rig drive motor and fuel pumps.

2. Temperature Controllers - 2 each for fuel barrel and injector nozzle wall-mounted.

3. Rocker Arm Oiling System - Drip system uses REO-191 (AL-6211-L) filled daily with oil squirt can.

4. Hand Wheel - Used to set rpm (1000 rpm) on electronic tachometer.

5. Micrometer Rack Control - Used to set fuel time at 31.5 mL min. Turn clockwise to increase fuel flow.

6. Fuel Return Valve - Sets return pressure to 30 psi.

7. Red Light is injector power indicator - Red = Power on to system.

8. Timer - Set red pointer to 15 min. cycle on-off timer.

9. Clock + Manual Switch - When in **clock position,** the rig starts and stops automatically (both the fuel pump and the drive motor). When in the **manual position,** the drive motor is started and stopped using start/stop buttons. The pump must be started using pump switch.

10. Fuel Pump Switch - Used to start and stop fuel pump when in the manual mode. Also used to pump solvents during cleanup procedure.

11. Fuel Return Pressure Gauge - This is the only pressure gauge monitored - 30 psi.

12. Fuel Time Valve - Two-way valve for fuel time sampling.

Attachment D (Cont'd)

13. Fuel Drain Valve - Located in front of fuel filter housing; used to drain system at E.O.T. and during cleanup procedure.

14. Temperature Controller at Base of Fuel Barrel - Does not need daily adjustment - it stays set at No. 8 for day and night operation - indicator light flashes off and on.

APPENDIX B

CLR-D Bosch APE 113 Injector Fouling Bench Test (IFBT) Cyclic Procedure

CLR-D BOSCH APE 113 INJECTOR FOULING BENCH TEST (IFBT) CYCLIC PROCEDURE

1. Preparation for Test

Prior to the test, the injector is examined for injection pressure and leakdown time on the jerk-pump machine (Attachment A). Additional tests include a nozzle airflow check (Attachment B), and a TDR spun rating for baseline data of a clean pintle/plunger. This data must be recorded and maintained throughout the test. The test fuel undergoes a battery of tests listed in Table 1.

TABLE 1. FUEL TESTS

Color, ASTM D 1500
JFTOT, ASTM D 3241, Breakpoint
Particulate Contamination, ASTM D 2276
Accelerated Stability, ASTM D 2274
Steam Jet Gum, ASTM D 381
Accelerated Stability, 150°C Test
Carbon Residue, 10% Bottoms, D 524

2. Procedure

Procure 13 gallons of the test fuel. One gallon is sent to the laboratory for testing, and 12 gallons are used for the injector rig test.

The CLR-D Bosch Rig controls are listed in Attachment C.

The injector rig is operated in the **automatic cyclic mode,** which automatically turns off the injector rig after 15 minutes. The injector rig remains off for another 15 minutes and then turns back on automatically. This procedure is repeated throughout the test. The injector is operated at the condition described in Table 2.

Record test number of CLR-D Bosch APE 113 Injector Fouling Bench Test in a log book to be kept by the injector rig. Use the letter B after test number to indicate the injector rig used is the Bosch APE 113. Table 3 lists the information to be recorded in the IFBT log book. Figure 1 illustrates the daily log book requirements.

TABLE 2. CLR-D BOSCH APE 113 IFBT OPERATING CONDITIONS FOR 40 HOURS (8 PER DAY)

	On 15 Minutes	Off 15 Minutes
Speed, rpm	1000	0
Fuel Flow, gal/hr	0.5	0
Fuel Spray Temp, °C (°F)	260 (500)*	Record
Temperature of Nozzle Tip Heating Block, °C (°F)	288 (550)	Record
Fuel Reservoir Temp, °C (°F)	79 (175)	79 (175)

* Target temperature.

TABLE 3. LOG BOOK INFORMATION

Test number

Test fuel by AL-Code

Test fuel description

Date test starts

Date test ends

Total hours of test

First two hours; then approximately each 2 hours for an on-and-off cycle record as follows:

- Ambient temperature
- Humidity
- Test hour
- Speed, rpm
- Time of day
- Barometric pressure
- Wet bulb temperature
- Spray temperature
- Nozzle body heating block temperature
- Nozzle tip heating block temperature
- Fuel reservoir temperature
- Fuel Flow

CLR–D BOSCH APE 113 INJECTOR FOULING BENCH TEST

Test No.________ Date________ Technician________ Page No.________

Test Fuel AL–Code________

Test Fuel Description________

Date Test Starts________ Date Test Ends________ Total Hours of Test________

Test Hour								
Time of Day								
Barometric Pressure, in Hg								
Ambient Temperature, Deg. F								
Wet Bulb, Deg. F								
Relative Humidity. %								
Speed, RPM								
Fuel Reservoir Temperature, Deg. F								
Spray Temperature, Deg. F								
Nozzle Body Heating Block Temperature, Deg. F								
Nozzle Tip Heating Block Temperature, Deg. F								
Fuel Flow, mL/Min. (31.5)								

FIGURE 1. CLR-D BOSCH APE 113 INJECTOR FOULING BENCH TEST LOG SHEET

The fuel lines in the injector rig should be stainless steel, and the fuel reservoir should be made of stainless steel. Copper or brass must not be allowed to come in contact with the test fuel at any time. The reservoir must be clean and able to maintain a fuel temperature of 79°C (175°F) during the daily test and 50°C (122°F) during the time rig is shutdown between daily test runs.

A digital readout thermometer is adequate if personnel are available to check the temperature periodically during the test run.

The injector test is run at maximum temperature for eight hours a day, as listed in Table 4, to enable a 40-hour test to be completed within one week (5 successive workdays). To allow for cool-down time, all heaters except the fuel reservoir, will be turned off during the last 15 minutes of the eighth hour each day.

At the end of the test, save approximately one gallon of test fuel from the fuel reservoir for further laboratory analyses. Table 5 contains the end-of-test cleanup procedure for the ignition rig. The test fuel undergoes a series of tests listed in Table 6.

Post-test performance evaluations include the evaluations of the injection pressure and leakdown time (Attachment A), plus the airflow test for the determination of nozzle hole plugging (Attachment B). The airflow evaluation is a modification of the ISO 4010-1977(E) standard.

Also, following the completion of the test, the pintle/plungers are rated for deposition by the methods listed in Table 7 and compared to their respective before-test measurements. Results are then listed in the work sheets as illustrated in Figure 2. Pintle should always remain wetted by Jet-A except during evaluations (heptane washing is permissible before each evaluation).

TABLE 4. CLR-D BOSCH DAILY OPERATION PROCEDURE

1. At 7:30, turn fuel barrel temperature controller to 175°F.

2. Check oil level in Bosch injector pump (uses REO 191: AL-6211-L).

3. Check oil level in speed drive unit (uses 40 wt AL-15478-L).

4. Start test at 8:00 AM, turn on switches at load center and power up temperature controllers to test conditions. First 15 minutes of cycle is heat soak.

5. Turn Manual-Off-Automatic switch to automatic-red power light comes on.

6. Adjust rpm to 1000.

7. Check fuel flow rate. Place graduated cylinder under fuel time valve. Open valve and collect 20 mL fuel. When fuel level reaches 20 mL, mark, start timer and time flow for 1 minute. Close valve. Let collected fuel cool and read volume collected (0.5 gal/hr = 31.5 mL/min). Adjust flow as needed.

8. Fill in the necessary log book information.

9. Check fuel flow every hour.

10. Adjust rpm, fuel flow, and temperature controller as required.

11. During the last 15 minutes of run cycle, turn off nozzle body, nozzle tip controllers, turn fuel barrel controller down to 122°F. Stop at 8 hours (4:00 PM).

12. Stop recorder. Turn automatic switch to off. Turn off all switches at load center **except** for fuel barrel, which stays at 122°F overnight.

    Note: **At the end of the 40-hour test, a 1-gallon sample of test fuel is taken from the fuel reservoir, properly labeled, and taken to chem lab for tests.**

TABLE 5. BOSCH INJECTOR RIG END-OF-TEST CLEANUP PROCEDURE

1. When the system has cooled to ambient temperature, remove the fuel filter element and save in a sealed can.
2. Clean filter housing and reinstall without filter element.
3. Disconnect both fuel lines from the lid of the fuel drum and remove the lid. Remove fuel line attached to underside of lid and reconnect to pump inlet line. The lid is not used during cleanup. Pump any remaining fuel to waste container.
4. Wash down the inside walls of fuel drum with approximately 1000 mL of iso-octane.
5. Open drain valve and using electric fuel pump, drain the washings to a slop container. Stop pump.
6. Close the drain valve and add approximately 2000 mL of fresh iso-octane to fuel drum.
7. Place fuel bypass return line in slop can and pump the washings through the system and into waste container. Note: **The return line valve might have to be adjusted to get more flow at this point.**

DO NOT START THE BOSCH INJECTOR PUMP

8. When the return washings look clean, open the drain valve and empty the fuel drum. Stop pump.
9. Drain the iso-octane from the fuel filter housing.
10. Wash down the insides of fuel drum with approximately 1000 mL of TAM.
11. Repeat Step Nos. 5 through 9 using TAM as the wash.
12. Pour approximately 2000 mL of neat Cat 1H or the next test fuel into fuel drum and circulate through the system into waste container to remove any solvents remaining in the system.
13. When the system is pumped dry, install a new filter element for the next test.

TABLE 6. AFTER IFBT TEST FUEL ANALYSIS

Color, ASTM D 1500

Visual, ASTM D 4176

JFTOT, ASTM D 3241, Breakpoint Temperature

Particulate Contamination, ASTM D 2276

Steam Jet Gum, ASTM D 381

Total Acid Number, ASTM D 664

Carbon Residue, 10% Bottoms, ASTM D 524

TABLE 7. IFBT DEPOSITION RATING*

Visual CRC lacquer demerit scale

JFTOT visual rating scale

TDR spun rating

Dielectric breakdown by Deposit Measuring Device (DMD)

Stereooptical examination plus micro DMD

* **NOTE:** Prior to testing, rinse the pintle with heptane to remove residual fuel and air dry. After each test, rewet the pintle with Jet-A fuel before replacing in its respective case.

CLR–D/BOSCH INJECTOR
IFBT INSPECTION WORKSHEET

DATE ____________ TEST NO. ____________ TEST HOURS ____________ INSPECTOR ____________

FUEL AL– NO. AND DESCRIPTION ____

TEST	TYP./REF.	BEFORE	AFTER
INJECTION PRESSURE PSI	2500		
SPRAY PATTERN	REPORT		
AIR FLOW CC/MIN.	REPORT		

PINTLE MERIT RATING		
RUBBING		
AREA	RATE	MERIT
	TOTAL	
NON–RUBBING		
AREA	RATE	MERIT
	TOTAL	
TIP		
AREA	RATE	MERIT
	TOTAL	

STATION	TDR SPUN RATING BEFORE	AFTER	CALC. VALUE

DIELECTRIC BREAKDOWN

STATION	0	90	180	270	AVG.

CSLI

FIGURE 2. CLR-D/BOSCH INJECTOR
IFBT INSPECTION WORK SHEET

Attachment A
CLR PRESSURE AND SPRAY PATTERN PROCEDURE

1. Install CLR Injector into holder on tester.

2. Check the level of calibration fluid in tester, adjust level if necessary.
   Note: **Do not use diesel fuel as calibration fluid.***

3. Open the valve to the pressure gauge.

4. Pump handle slowly and build up pressure to set injector pop-off pressure at 2500 psi (injector limits are 2000 to 3000 psi). If pop-off pressure is correct, proceed to Step No. 5. If not, loosen the locknut on injector top and adjust screw for proper pressure and retighten locknut.

5. Close the valve to the pressure gauge.

6. Jerk the pump handle and check the spray pattern for good atomization. (You should hear a "cracking" sound from the injector as well as good atomization.) If all looks good, proceed to Step No. 7. If not, remove the injector from the tester and remove spray nozzle from the injector. Lap the nozzle with tallow on blocks using a figure 8 polishing motion. After polishing, reinstall and repeat Step No. 6.

7. Open valve to pressure gauge.

8. Repeat Step No. 4 for pressure pop-off limits recheck.

* Calibration fluid used is: AL-12688-L
Viscor 1487
Viscosity Oil Co.

Attachment B

AIRFLOW TESTER PROCEDURE

1. Remove the Bell jar from the tester and lay on its side to keep the rubber gasket clean.

2. Place the "O" ring on the spray assembly and install it in the base of the tester.

3. Attach the adaptor to the pintle stem and tighten the set screw. The adaptor should not prevent the pintle from closing completely.

4. Remove the pintle from the spray assembly.

5. Attach the micrometer to the spray assembly adaptor plate (the circular grooved side of plate faces down) and semitight the nut.

6. Attach the adaptor plate and micrometer to the tester and tighten the screws. The "O" ring on the spray assembly must make a good seal.

7. Swing the micrometer to the side to provide access to the spray assembly. Slide the spring on the pintle and insert pintle into spray assembly. The pintle should move down and spring up freely.

8. While holding pintle in down position, swing the micrometer in place directly over the pintle adaptor and tighten the holding nut on the micrometer.

9. Attach the drive belt and install the Bell jar.

10. Close the inlet valve on the flow meter, have the pintle in the up position and open the vacuum valve. Pull as much vacuum as the system will pull (30 in.) and hold for approximately 10 min. to assure a good seal.

11. Close the vacuum valve and open the intake valve. When pressure returns to zero, close the intake valve.

Attachment B (Cont'd)

12. Put the pintle in the closed position (down) and open the vacuum valve. When the gauge reads 30 in., open the intake valve all the way. There should be no indicated airflow at this point.

13. Slowly raise the pintle using the micrometer in small increments (0.005 to 0.010 in.) and record airflow versus micrometer setting. The maximum airflow is reached when the pintle is all the way up. Convert flow meter reading to cc/min.

14. Close the vacuum valve and open the intake valve. When pressure returns to zero, remove the Bell jar.

Attachment C

CLR-D BOSCH RIG CONTROLS

1. Power is supplied by a large power cord and wall plug. The circuit breaker is in test cell No. 7 and is No. 7. This powers a load center with switches for fuel barrel, nozzle body, nozzle tip, fuel pump and recorder.

2. Temperature Controllers - 3 each for fuel barrel, nozzle tip, nozzle body temperature control.

3. Hand Wheel - Used to set rpm on electronic tachometer (1000 rpm).

4. Micrometer Rack Control - Used to set fuel time at 31.5 mL/min. Turn clockwise to decrease flow.

5. Fuel Return Valve - No pressure gauge in system - adjust to low return flow.

6. Red Light is injector power indicator, Red = Power on to system.

7. Timer - Set red pointer to 15 minutes for on-off cycle period.

8. Manual - off-Automatic Switch - In manual mode, rig runs constantly - in off, the power is off to drive motor - in automatic, the rig starts and stops automatically.

9. Fuel Pump Switch - Located on load center - pump runs constantly, does not cycle with drive motor when turned on.

10. Fuel Time Valve - A two-way valve for fuel time sampling.

11. Fuel Drain Valve - Located in front of fuel filter housing; used to drain the system at E.O.T. and during cleanup procedure.

12. Temperature Controller at Base of Fuel Barrel - Does not need daily adjustment - it stays set at No. 7 for day and night operation - indicator light flashes off and on.

APPENDIX C

Tables of Data Including IFB Test Results, Fuels Analysis, and JFTOT Data

TABLE C-1. Summary of Detroit Diesel IFB Test Data

	Set 1			Set 2					
Test Number:	Test 6-D	Test 8-D	Test 9-D	Test 12-D	Test 13-D	Test 14-D	Test 15-D	Test 16-D	Test 17-D
Fuel Identification No.:	AL-12624-F	AL-12624-F	Al-12624-F	AL-15482-F	AL-16823-F	AL-17204-F	AL-15542-F	AL-15542-F	AL-16127-F
Fuel Description:	1% Sulfur	1% Sulfur	1% Sulfur	Ref No. 2 Diesel (R2DF)	Jet A + 3% S (TBDS)	R2DF	1% S, without Additives	1% S, without Additives	Jet A
Date:	8/86	10/86	11/86	1/88	2/88	2/88	4/88	4/88	5/88
Test Mode/Fuel Volume, gal.	Continuous/21	Cyclic/12	Cyclic/12	Cyclic/12	Cyclic/12	Cyclic/12	Cyclic/12	Cyclic/12	Cyclic/12
Nozzle Tip Heating Block, °F	600	600	550	600	600	600	600	550	600
Test Hours	40	40	40	40	3.25	40	16	40	31.5(out of fuel)
Fuel JFTOT BPT, °C	204	204	204	250	280	260	232	232	>280
DMD Deposit Volume, JFTOT at 260°C, cc × 10^{-7}	3235	3235	3235	151	84	<50	104	104	<50
Pintle Merit Rating: (10 = Clean)									
Rubbing	4.0	1.6	4.3	2.0	3.4	1.4	4.6	2.5	2.1
Nonrubbing	1.3	3.9	2.3	1.8	4.3	1.9	1.4	2.1	1.0
Tip	4.0	2.7	4.9	1.4	1.2	1.4	1.1	1.7	1.7
Total (30 = Clean)	9.3	8.2	11.5	5.2	8.9	4.7	7.1	6.3	4.8
Air Flow, cc/min									
Before	ND	ND	1240(E)	1460	1425	1570	1320	1640	1350
After	ND	ND	1070(E)	1320*	**	1570*	1390*	1570*	1350*
Percent Loss	ND	ND	ND	10	**	0	0	4	0
TDR Spun Deposit Rating									
Rubbing, max	46	45	51	38	**	30	***	45	47
Nonrubbing, max	43	38	38	36	**	35	***	34	37
Max. Thickness, DMD, Avg Volts	918 at Tip	850 at Tip	1062 at Tip	0	ND	0	***	ND	ND
Pressure Reference Value									
Before	158	134	138	130	126	128	127	136	147
After	136	126	138	**	**	**	***	155	130
Leakdown dP: 15 seconds									
Before	45	42	56	132	180	79	118	53	165
After	31	41	35	**	**	**	***	65	107
Fuel Flow, mL/1000 strokes									
Before	93	93	93	100	100	100	100	96	97
After	92	95	92	**	**	**	***	97	98
Spray Pattern									
Before	Good	Good	Good	Good	Good	Very Good	Very Good	Very Good	Very Good
After	Weak	Fair	Good	**	**	Good	***	Very Good	Very Good

ND = Not Determined.
(E) Estimated from old data on new flow meter chart.
*Flow rated with pintle removed.
**Pintle broken, unable to rate.
*** Pintle seized open, unable to rate. Nozzle body cut open to retrieve pintle for merit rating.

TABLE C-1. Summary of Detroit Diesel IFB Test Data (Cont'd)

	Set 3							
Test Number:	Test 18-D	Test 19-D	Test 20-D	Test 21-D	Test 22-D	Test 23-D	Test 24-D	Test 25-D
Fuel Identification No.:	AL-18516-F	AL-18516-F	AL-18516-TB2	AL-18516-TB4	AL-18954-F	AL-19053-F	AL-19062-F	FL-1325-F
Fuel Description:	Ref No. 2 Diesel (R2DF)	R2DF	R2DF + Test Mix #2	R2DF + Test Mix #4	R2DF + 10% LCGO	R2DF + 0.35% MFO	JP-8	3:1 Burner Oil # 2 + Additive
Date:	3/89	3/89	4/89	5/89	8/89	10/89	11/89	3/90
Test Mode/Fuel Volume, gal.	Cyclic/12	Cyclic/12	Cyclic/12	Cyclic/12	Cyclic/12	Cyclic/12	Cyclic/12	Cyclic/12
Nozzle Tip Heating Block, °F	600	550	550	550	550	550	550	550
Test Hours	40	40	40	40	40	40	40	40
Fuel JFTOT BPT, °C	250	250	260	230	215	215	>300	215
DMD Deposit Volume, JFTOT at 260°C, cc × 10^{-7}	500	500	100	60	5100	1100	0	1400
Pintle Merit Rating: (10 = Clean)								
Rubbing	6.8	7.4	5.0	3.6	2.0	1.0	7.0	3.6
Nonrubbing	2.0	2.5	3.6	3.1	1.0	1.0	7.0	2.0
Tip	2.0	2.0	3.0	3.0	1.0	1.0	3.0	2.0
Total (30 = Clean)	10.8	11.9	11.6	9.7	4.0	3.0	17.0	7.6
Air Flow, cc/min								
Before	1170	1030	880	1320	1320	1320	1240	1170
After	1100*	880	880*	1320*	1320*	1240*	1240	1100*
Percent Loss	6	15	0	0	0	6	0	6
TDR Spun Deposit Rating								
Rubbing, max	56	45	36	40	40	40	26	41
Nonrubbing, max	50	44	32	41	35	39	36	28
Max. Thickness, DMD, Avg Volts,								
Sum of Rubbing Area	0	0	4	4	0	178**	451**	42
Rubbing, max	0	0	3	3	0	76	208**	41
Sum of Nonrubbing Area	15	1	11	2	40	151**	557**	301
Nonrubbing, max	7	1	4	2	7	48	105**	99
Sum of Tip Area	6	1	8	9	14	192**	4	32
Tip, max	4	1	7	7	7	196	2	26
Pressure Reference Value								
Before	132	128	128	155	155	148	148	155
After	128	128	128	155	100	146	144	138
Leakdown dP: 15 seconds								
Before	49.5	40.0	81.0	70.0	160	100	70.0	105
After	39.0	68.0	41.0	120	146	112	80.0	80
Fuel Flow, mL/1000 strokes								
Before	97	92	90	94	83	86	86	86
After	96	91	91	86	82	86	86	84
Spray Pattern								
Before	Good	Good	Good	Good	Good	Good	Good	Good
After	Good	Good	Good	Good	Good	Good	Good	Good

*Pintle stuck. flow rated with pintle removed.

**High value may be due to metal surface flaw, as heavy deposit is not apparent; different technician.

TABLE C-1. Summary of Detroit Diesel IFB Test Data (Cont'd)

	Set 3			
Test Number:	Test 26-D	Test 27-D	Test 28-D	Test 29-D
Fuel Identification No.:	AL-18987-F	AL-19393-F	AL-15542-F	AL-19444-F
Fuel Description:	R2DF	JP-8	1% Sulfur, w/o Additives	1% Sulfur, w/o Additives
Date:	5/90	6/90	7/90	7/90
Test Mode/Fuel Volume, gal.	Cyclic/24	Cyclic/24	Cyclic/24	Cyclic/24
Nozzle Tip Heating Block, °F	550	550	550	550
Test Hours	80	80	36.5	80
Fuel JFTOT BPT, °C	270	300	250	215
DMD Deposit Volume, JFTOT at 260°C, cc × 10^{-7}	0	0	0	1769
Pintle Merit Rating (10 = Clean)				
Rubbing	2.5	6.0	6.0	3.0
Nonrubbing	2.5	5.0	6.0	3.8
Tip	2.5	5.0	6.0	2.0
Total (30 = Clean)	7.5	16.0	18.0	8.8
Air Flow, cc/min				
Before	1170	1240	1170	1170
After	1100*	1170*	1100*	800*
Percent Loss	6	6	6	32
TDR Spun Deposit Rating				
Rubbing, max	56	30	41	**
Nonrubbing, max	39	34	34	**
Max. Thickness, DMD, Avg. Volts				
Sum of Rubbing Area	31	ND	**	**
Rubbing, max	28	ND	**	**
Sum of Nonrubbing Area	262	ND	**	**
Nonrubbing, max	106	ND	**	**
Sum of Tip Area	3	ND	**	**
Tip, max	3	ND	**	**
Pressure Reference Value				
Before	146	144	146	144
After	148	136	***	***
Leakdown dP: 15 seconds				
Before	86	88	88	15
After	70	44	***	***
Fuel Flow, mL/1000 strokes				
Before	86	86	100	99
After	86	86	120	120
Spray Pattern				
Before	Good	Good	Good	Good
After	Good	Good	Weak	Very Weak

*Pintle stuck; flow rated with pintle removed.
**Unable to rate: deposit flakes off pintle.
***Unable to rate; pintle stuck open.

TABLE C-2. Summary of Bosch APE 113 /FB Test Data

	Set 1			Set 2					
Test Number:	Test 5-B	Test 8 B	Test 9B	Test 12-B	Test 13-B	Test 14-B	Test 15-B	Test 16-B	Test 17-B
Fuel Identification No.:	AL-12624-F	AL-12624-F	AL-12624-F	AL-15482-F	AL-16823-F	AL-17204-F	AL-15542-F	AL-15542-F	AL-16127-F
Fuel Description:	1% Sulfur	1% Sulfur	1% Sulfur	Ref No. 2 Diesel	Jet A + 3% S (TBDS)	Ref No. 2 Diesel	1% S, without Additives	1% S, without Additives	Jet A
Date:	8/86	10/86	11/86	1/88	2/88	2/88	4/88	4/88	5/88
Test Mode/Fuel Volume, gal	Continuous/21	Cyclic/12	Cyclic/12	Cyclic/12	Cyclic/12	Cyclic/12	Cyclic/12	Cyclic/12	Cyclic/12
Nozzle Tip Heating Block, °F	560	560	500	560	560	560	560	500	560
Test Hours	40	40	40	40	15.5	40	40	40	34(Out of fuel)
Fuel JFTOT BPT, °C	204	204	204	254	280	260	232	232	>280
DMD Deposit Volume, JFTOT at 260°C, cc × 10^{-7}	3235	3235	3235	151	84	<50	104	104	<50
Pintle Merit Rating: (10 = Clean)									
Rubbing	8.1	5.6	4.3	5.4	3.2	6.9	4.4	5.9	4.5
Nonrubbing	8.1	2.1	2.3	2.0	2.1	3.0	3.3	3.2	1.3
Tip	5.4	4.7	4.9	2.5	5.0	2.9	2.0	2.2	2.2
Total (30 = Clean)	21.6	12.4	11.5	9.9	10.3	12.8	9.7	11.3	8.0
Air Flow, cc/min									
Before	2438	ND	2245	2440	2220	2330	2290	2440	2370
After	2350	ND	2257	2440	2120*	2080*	2550*	2440*	2440
TDR Spun Deposit Rating									
Rubbing, max	46	45	30	7	45	6	58	35	34
Nonrubbing, max	43	38	37	25	26	40	34	39	32
Max. Thickness, DMD, Avg. Volts	683 at Tip	945 at Tip	447 at Tip	10 at Tip	0	520 at Tip	ND	ND	ND
Injection Pressure, psi									
Before	2500	2500	2500	2500	2500	2500	2500	2500	2500
After	2500	2400	2475	2500	**	**	2500	2500	2450
Spray Pattern									
Before	Very Good	Very Good	Very Good	Very Good	Very Good	Very Good	Very Good	Very Good	Very Good
After	Very Good	Very Good	Very Good	Very Good	**	**	Good	Very Good	Good

ND = Not Determined

*Flow rated with pintle removed.

**Pintle seized open, unable to rate.

TABLE C-2. Summary of Bosch APE 113 IFB Test Data (Cont'd)

	Set 3							
Test Number:	Test 18-B	Test 19-B	Test 20-B	Test 21-B	Test 22-B	Test 23-B	Test 24-B	Test 25-B
Fuel Identification No.:	AL-18516-F	AL-18516-F	AL-18516-TB2	AL-18516-TB4	AL-18954-F	AL-19053-F	AL-19062-F	FL-1325-F
Fuel Description:	Ref No. 2 Diesel	Ref No. 2 Diesel	R2DF + Test Mix #2	R2DF + Test Mix #4	R2DF + 10% LCGO	R2DF + 0.35% MFO	JP-8	3:1 # 2 Burner Oil + Additive
Date:	3/89	3/89	4/89	5/89	8/89	10/89	11/89	3/90
Test Mode/Fuel Volume, gal	Cyclic/12	Cyclic/12	Cyclic/12	Cyclic/12	Cyclic/12	Cyclic/12	Cyclic/12	Cyclic/12
Nozzle Tip Heating Block, °F	600	550	550	550	550	550	550	550
Test Hours	40	40	40	40	40	40	40	40
Fuel JFTOT BPT, °C	250	250	260	230	215	215	>300	215
DMD Deposit Volume, JFTOT at 260°C, cc × 10^{-7}	500	500	100	60	5100	1100	0	1400
Pintle Merit Rating: (10 = Clean)								
Rubbing	7.9	7.4	8.4	8.2	8.6	6.8	7.4	7.5
Nonrubbing	3.2	2.5	4.9	4.8	1.6	2.8	3.4	5.0
Tip	2.0	2.0	3.0	3.5	1.0	2.0	2.0	2.0
Total (30 = Clean)	13.1	11.9	16.3	16.5	11.2	11.6	12.8	14.5
Air Flow, cc/min								
Before	2330	2330	2260	2340	2330	2330	2260	2260
After	2040	2260*	2260*	2260	2260*	2330*	1890	2260*
Percent Loss	12	3	0	3	3	0	16	0
TDR Spun Deposit Rating								
Rubbing, max	39	24	10	26	28	22	42	27
Nonrubbing, max	33	32	34	29	35	33	29	34
Max. Thickness, DMD, Avg. Volts								
Sum of Rubbing Area	71	17	0	0	4	0	184**	314
Rubbing, max	71	17	0	0	4	0	82	76
Sum of Nonrubbing Area	37	5	31	46	27	268**	429**	440
Nonrubbing, max	30	3	19	33	8	88	95	163
Sum of Tip Area	0	0	27	45	135	147**	457**	167
Tip, max	0	0	27	32	133	78	77	117
Injection Pressure, psi								
Before	2500	2500	2500	2500	2500	2500	2500	2500
After	2600	2500	2500	2500	2400	2400	2500	2450
Spray Pattern								
Before	Good	Good	Good	Good	Good	Good	Good	Good
After	Good	Good	Good	Good	Good	Good	Good	Good

*Pintle stuck; flow rated with pintle removed.

**High value may be due to metal surface flaw, as heavy deposit is not apparent; different technician.

TABLE C-2. Summary of Bosch APE 113 IFB Test Data (Cont'd)

	Set 3			
Test Number:	Test 26-B	Test 27-B	Test 28-B	Test 29-B
Fuel Identification No.:	AL-18987-F	AL-19393-F	AL-15542-F	AL-19444-F
Fuel Description:	Ref No. 2 Diesel	JP-8	1% Sulfur, w/o Additives	1% Sulfur, w/o Additives
Date:	5/90	6/90	7/90	7/90
Test Mode/Fuel Volume, gal.	Cyclic/24	Cyclic/24	Cyclic/24	Cyclic/12
Nozzle Tip Heating Block, °F	550	550	550	550
Test Hours	80	80	80	40
Fuel JFTOT BPT, °C	270	300	250	215
DMD Deposit Volume, JFTOT at 260°C, cc × 10^{-7}	0	0	0	1769
Pintle Merit Rating: (10 = Clean)				
Rubbing	7.4	7.3	7.2	7.2
Nonrubbing	4.0	3.4	1.5	3.5
Tip	2.0	2.0	2.0	2.0
Total (30 = Clean)	13.4	12.7	10.7	12.7
Air Flow, cc/min				
Before	2260	2260	2190	1530
After	2260*	2190*	2120*	2120*
Percent Loss	0	3	3	0
TDR Spun Deposit Rating				
Rubbing, max	40	34	**	**
Nonrubbing, max	32	30	**	**
Max. Thickness, DMD, Avg. Volts				
Sum of Rubbing Area	95	ND	**	**
Rubbing, max	65	ND	**	**
Sum of Nonrubbing Areas	447	ND	**	**
Nonrubbing, max	99	ND	**	**
Sum of Tip Area	16	ND	**	**
Tip, max	16	ND	**	**
Injection Pressure, psi				
Before	2500	2500	2500	2500
After	2450	2500	2400	2500
Spray Pattern				
Before	Good	Good	Good	Good
After	Good	Good	Good	Good

ND = Not determined.

*Pintle stuck; flow rated with pintle removed.

***Unable to rate; deposit flakes off pintle.*

(This page intentionally left blank.)

TABLE C-3. Fuel Analysis Before IFB Tests

Fuel Description	IFBT Test No.	Total Insolubles, D 2274, mg/100 mL	Particulates, D 2276, mg/L	Gum, D 381, mg/100 mL	Carbon Residue, mass%	D 1500, Color	Total Acid No., mgKOH/g	Stability by Oxygen Overpressure 16 Hours, mg/100 mL	32 Hours, mg/100 mL
AL-12624-F 1% Sulfur	6 8 9	6.8	12.0	27.3	ND	4.5	ND	ND	ND
AL-15482-F (Drum #12) Reference No. 2 Diesel (R2DF)	12	6.7	3.3	4.2	ND	1.5	ND	ND	ND
AL-16823-F Jet A + 3% S (TBDS)	13	0.3	3.3	1.4	ND	<0.5	ND	ND	ND
AL-17204-F (1 of 3) R2DF	14	1.2	1.7	3.9	ND	1.5	ND	ND	ND
AL-15542-F 1% Sulfur w/o additives	15 16	2.0	27.5	7.0	ND	1.5	ND	ND	ND
AL-16127-F Jet A	17	<0.1	2.4	1.1	ND	0.5	ND	ND	ND
AL-18516-F R2DF	18 19	0.4	1.3	3.0	0.10	1.0	0.14	2.0	ND
AL-18516-TB2 R2DF + Test Blend No. 2	20	0.4	3.1	1.3	0.10	1.0	0.16	1.7	ND
AL-18516-TB4 R2DF + Test Blend No. 4	21	0.4	4.6	2.4	0.11	0.5	0.19	1.8	ND
AL-18954-F R2DF + 10% Light Coker Gas Oil	22	4.9	15.6	8.9	0.16	7.5	0.19	6.8	ND
AL-19053-F R2DF + 0.35% Marine Fuel Oil	23	0.3	92.7	153.9	0.43	>8.0	0.25	8.1	ND
AL-19062-F JP-8	24	0.1	0.6	0.2	0.06	0.5	0.01	0.6	ND
FL-1325-F 3 part Burner Oil #2 + 1 part Additive	25	0.3	0.4	11.9	0.22	4.0	<0.01	2.7	ND
AL-18987-F R2DF	26	0.1	4.5	0.6	0.09	<0.5	0.08	1.9	2.7
AL-19393-F JP-8	27	0.1	0.5	1.0	0.03	0.5	0.02	0.5	0.4
AL-15542-F† 1% Sulfur Fuel w/o Additives	28	2.1	1.6	3.8	0.13	1.5	0.04	14.0	16.2
AL-19444-F 1% Sulfur Fuel w/o Additives	29	2.0	13.3	5.0	0.16	1.5	0.03	11.3	12.4

(A) = Abnormal
(P) = Peacock
*No prefilter used due to plugging problem with this blend.
†Repeat
ND = Not Determined

JFTOT Results Before IFBT Tests

Test No.	Temp, °C	Change in Pressure, mm of Hg	TDR Spun Deposit Rating at Station, mm	Visual	Max. Thickness, DMD, cm × 10^{-7}	Vol. of Deposit, DMD, cc × 10^{-7}	BPT, Code 3, °C
1216-J	204	125 in 123 min	10 at 43	3	68 at 34	82	204
1217-J	232	125 in 32 min	20 at 40	4(P)	175 at 42	254	
1219-J	260	125 in 13 min	49 at 46	>4(P)	2564 at 40	3235	
51-T	232	0	8 at 38	2(A)	<50	74	250
50-T	260	125 in 39 min	16 at 28	>4 (A)	77 at 42	151	
59-T	260	125 in 145 min	19 at 30	>4 (A)	77 at 20	262	
49-T	280	125 in 39 min	30 at 46	4 (P)	331 at 42	456	
7-B	260	16 in 150 min	1 at 49	1	<50	84	280
78-T	280	104 in 150 min	12 at 46	3 (Spot)	<50	<50	
9-B	232	0	8 at 34-42	2	<50	<50	250
61-T	260	0	15 at 38-42	3	<50	<50	
79-T	280	125 in 98 min	27 at 42	4 (P)	280 at 46	273	
75-T	232	0	22 at 39	3	57 at 48	<50	232
73-T	260	125 in 105 min	22 at 42	>4 (P)	88 at 42	104	
74-T	280	125 in 37 min	58+ at 34-48	>4 (P)	1705 at 38	2644	
45-T	260	0	0	1	22 at 28	<50	>280
48-T	280	0	4 at 49	1	22 at 34	<50	
109-T	232	0	3 at 40	2	68 at 24	185	250
54-B	245	0	5 at 44	2	<50	<50	
55-B	250	0	17 at 42	3	<50	<50	
111-T	260	125 in 117 min	18 at 40	4 (P)	540 at 40	514	
58-B	232	0	4 at 44	2	<50	<50	260
59-B	245	0	6 at 46	2	<50	<50	
60-B	260	5.0 in 150 min	10 at 42	3 (A)	71 at 22	95	
247-T	230	0	11 at 42	3	<50	<50	230
246-T	240	125 in 137.2 min	17 at 46	4	<50	<50	
142-T	260	125 in 129.3 min	13 at 30	>4 (A)	77 at 42	63	
241-T	215	0	19 at 48	3	<50	<50	215
239-T	232	0	25 at 48	4 (P)	174 at 42	303	
171-T	260	125 in 8.2 min	50+ at 32-56	>4 (P)	2962 at 34	5148	
57-B*	215	125 in 41.4 min	27 at 38	3	<50	<50	215
194-T*	260	125 in 41.4 min	34 at 36-44	>4 (P)	551 at 40	1141	
198-T	260	0	0	1	<50	<50	>300
204-T	300	0	7 at 42-46	2	<50	<50	
44-B	200	0	0	1	<50	<50	215
51-B	215	0	17 at 44	3	<50	<50	
43-B	232	0	19 at 32	>4	<50	51	
40-B	260	0	37 at 44	4 (P)	654 at 40	1407	
56-B	260	0	4 at 40	1	<50	<50	270
248-T	270	10 in 150.0 min	16 at 36	3 (P)	<50	<50	
245-T	280	125 in 72.1 min	21 at 44	4 (P)	388 at 42	506	
249-T	260	0	0	1	<50	<50	300
250-T	280	0	0	2	<50	<50	
66-B	300	0	30 at 48	3	<50	<50	
256-T	250	0	10 at 44	3	<50	<50	250
64-B	260	0	26 at 36-42	<4	<50	<50	
252-T†	260	0	27 at 40-45	<4	<50	<50	
255-T	215	0	10 at 42	3	<50	<50	215
254-T	232	0	30 at 50	>4	<50	<50	
253-T	260	125 in 70.6 min	50+ at 34-50	>4 (P)	1091 at 42	1769	

TABLE C-4. Fuel Analysis After IFB Tests

Fuel Description	IFBT Test No.	IFBT Test Time, hr	Total Insolubles, D 2274-88, mg/100 mL	Particulates, D 2276, mg/L	Gum, D 381, mg/100 mL	Total Acid No., mgKOH/g	Carbon Residue, mass%	Visual Appearance	D 1500, Color
AL-12624-F	6-B	40	ND	74.9*	28.4	0.04	0.29	Dark	>8.0
1% Sulfur	6-D	40	ND	45.0*	39.8	0.02	0.24	Dark	>8.0
AL-12624-F	8-B	40	ND	26.5*	34.0	0.04	0.23	Dark	7.0
1% Sulfur	8-D	40	ND	8.8	43.3	0.02	0.20	Dark	5.5
AL-12624-F	9-B	40	ND	824.6	98.9	0.18	0.98	Dark	8.0
1% Sulfur	9-D	40	ND	1122.2	90.2	0.15	0.89	Dark	5.5
AL-15482-F (Drum #12)	12-B	40	ND	7.4	7.3	0.03	0.18	Sed/Br	2.5
Reference No. 2	12-D	40	ND	10.5	14.6	0.05	0.18	Sed/Br	3.5
Diesel (R2DF)									
AL-16823-F	13-B	15.5	ND	1.4	1.5	<0.01	0.08	Sed/Br	0.5
Jet A + 3% S (TBDS)	13-D	3.25	ND	0.8	1.7	<0.01	0.08	Sed/Br	0.5
AL-17204-F (1 of 3)	14-B	40	ND	3.6	9.3	0.09	0.14	Cl/Br	2.0
R2DF	14-D	40	ND	20.0*	16.4	0.08	0.15	Sed/Br	3.0
AL-15542-F (Drum 1)	15-B	40	ND	8.1	8.8	0.03	0.12	Sed/Br	2.5
1% Sulfur w/o additives	15-D	16	ND	5.7	8.6	0.03	0.14	Cl/Br	2.5
AL-15542-F (Drum 1)	16-B†	40	ND	7.6	11.5	0.03	0.13	Sed/Br	2.5
1% Sulfur w/o additives	16-D†	40	ND	18.3	16.2	0.03	0.15	Sed/Br	2.5
AL-16127-F	17-B	34‡	ND	4.4	1.4	0.02	0.08	Cl/Br	<0.5
Jet A	17-D	31.5‡	ND	13.3	2.7	0.01	0.07	Cl/Br	<0.5
AL-18516-F	18-B	40	0.3	1.1	2.9	0.08	0.12	Cl/Br	1.0
R2DF	18-D	40	1.0	4.6	2.8	0.08	0.11	CL/Br	1.0
AL-18516-F	19-B**	40	0.5	1.0	2.2	0.11	0.10	Cl/Br	1.0
R2DF	19-D**	40	0.7	0.7	2.9	0.10	0.10	Cl/Br	1.0
AL-18516-TB2 R2DF +	20-B	40	2.7	1.3	3.1	0.16	0.09	Cl/Br	1.0
Test Blend No. 2	20-D	40	2.0	0.5	2.9	0.16	0.08	Cl/Br	1.0
AL-18516-TB4 R2DF +	21-B	40	0.7	3.8	2.4	0.18	0.13	Cl/Br	1.0
Test Blend No. 4	21-D	40	2.1	0.7	2.7	0.17	0.12	Cl/Br	1.0
AL-18954-F	22-B	40	NES††	20.1	15.8	0.19	0.21	Dark	7.0
R2DF + 10% Light Coker	22-D	40	NES	11.6	29.3	0.19	0.22	Dark	7.0
Gas Oil									
AL-19053-F	23-B	40	0.3	14.6	158.0	0.10	0.45	Sed/Dark	>8.0
R2DF + 0.35% MFO	23-D	40	4.8	36.2	162.3	0.10	0.51	Sed/Dark	>8.0
AL-19062-F	24-B	40	0.1	0.3	0.8	0.02	0.05	Cl/Br	0.5
JP-8 (From Ft. Bliss)	24-D	40	0.1	0.4	1.1	0.02	0.06	Cl/Br	0.5
FL-1325-F	25-B	40	0.6	2.4	14.6	0.01	0.19	Sed/Br	4.5
3 Parts Burner Oil #2	25-D	40	0.9	10.1	19.8	0.01	0.19	Sed/Br	4.5
1 Part Additive									
AL-18987-F	26-B	80	0.4	0.7	0.3	0.08	0.10	Cl/Br	<0.5
R2DF	26-D	80	1.0	0.5	0.8	0.08	0.10	Cl/Br	<0.5
AL-19393-F	27-B	80	0.1	1.0	0.3	0.01	0.03	Cl/Br	0.5
JP8	27-D	80	0.2	1.1	2.5	0.01	0.06	Cl/Br	0.5
AL-15542-F	28-B	80	0.4	6.9	7.2	0.05	0.15	Sed/Br	2.5
1% Sulfur Reference Fuel	28-D	36.5	0.7	13.5	29.2	0.05	0.14	Sed/Br	2.5
w/o Additives									
AL-19444-F	29-B	40	2.3	3.6	6.4	0.04	0.13	Sed/Br	2.0
1% Sulfur Reference Fuel	29-D	80	0.5	7.1	10.1	0.05	0.14	Sed/Br	3.5
w/o Additives									

*Filter plugged at 300 mL.
†Spray temperature decreased from 500°F to 450°F.
‡Not enough fuel to complete 40 hour test.
**Temperature of nozzle tip heating block set at 550°F in procedure.
††NES = Not Enough Sample
(A) = Abnormal; (P)=Peacock
ND = Not Determined.
B = Bosch injector; D = Detroit Diesel injector

JFTOT Results After IFBT Tests

Test No.	Temp, °C	Change in Pressure, mm of Hg	TDR Spun Deposit Rating at Station, mm	Visual	Max. Thickness, DMD, cm X 10^{-7} at Station, mm	Volume of Deposit, DMD, cc X 10^{-7}
1366-T	204	111 in 150 min	19 at 51	>4(P)	<50	58
1367-G	204	0	14 at 51	>4(P)	<50	<50
1391-J	204	4 in 150 min	15 at 43	<4	<50	<50
1392-G	204	6 in 150 min	19 at 50	<4	<50	54
1400-J	204	125 in 143 min	13 at 43	<4	<50	<50
1401-G	204	125 in 92 min	16 at 48	>4(P)	<50	<50
3-B	260	0	24 at 10	<4 (A)	<50	<50
5-B	260	0	23 at 14	<4	<50	<50
6-B	260	101 in 125 min	0	1	<50	<50
8-B	260	46 in 150 min	0	<2	<50	60
69-T	260	0	12 at 40	3	<50	<50
71-T	260	125 in 150 min	22 at 30	>4 (A)	171 at 42	186
20-B	260	3 in 150 min	21 at 30	4 (A)	88 at 46	82
21-B	260	0	19 at 32	>4	<50	<50
25-B	260	0	18 at 30-34	>4	<50	<50
77-T	260	0	19 at 28	4	102 at 40	89
82-T	260	22 in 150 min	0	1	<50	58
83-T	260	0	4 at 4	1	<50	<50
118-T	260	125 in 137.8 min	13 at 30	>4 (A)	57 at 2	183
124-T	260	0	14 at 42	4 (P)	182 at 42	280
126-T	260	125 in 147.1 min	12 at 42	>4 (A)	185 at 38	345
127-T	260	0	17 at 40-44	4 (A)	65 at 40	165
131-T	260	125 in 79.6 min	16 at 30	>4 (P)	134 at 44	131
132-T	260	10 in 149.7 min	13 at 40-44	4 (P)	131 at 38	164
146-T	260	125 in 48.4 min	23 at 46	4 (P)	640 at 40	876
147-T	260	12 in 120.0 min	29 at 45	>4	1097 at 44	1455
172-T	260	125 in 7.1 min	50+ at 26-58	4 (P)	1991 at 32	4128
173-T	260	125 in 12.4 min	50+ at 32-58	>4 (P)	2191 at 36	4584
196-T	260	125 in 41.2 min	29 at 36	>4 (P)	320 at 40	599
197-T	260	125 in 76.0 min	27 at 34	>4 (P)	288 at 44	422
205-T	260	125 in 118.3 min	0	1	<50	<50
206-T	260	0	6 at 52	2	<50	<50
41-B	260	125 in 103.9 min	43 at 44	>4 (P)	620 at 40	1320
42-B	260	0	41 at 44	>4 (P)	400 at 40	902
63-B	260	0	9 at 44	2	<50	<50
62-B	260	0	13 at 44	3	<50	<50
65-B	260	0	0	2	<50	<50
251-T	260	0	7 at 42	2	<50	<50
257-T	260	0	23 at 44	<4	<50	<50
67-B	260	0	25 at 44	<4	<50	<50
68-B	260	125 in 146.5 min	19 at 46	4	<50	<50
258-T	260	0	18 at 25	4 (P)	<50	<50

TABLE C-5. Deposit Measuring Device (DMD) Evaluation of JFTOT

Base Fuel Code No.	Fuel Description	Total Insolubles, D2274-88, mg/100 mL	JFTOT Operating Conditions: Date	Test No.	Test Time, hr	Tube Metal
18516	Reference #2 Diesel Fuel (R2DF)	0.4	02-13-89	109-T	2.5	Al
			02-21-89	113-T	2.5	Al
			02-23-89	115-T	2.5	Al (4X)†
			05-02-90	54-B	2.5	Al
			05-03-90	55-B	2.5	Al
			02-16-89	111-T	2.5	Al
			02-22-89	114-T	2.5	Al
			02-24-89	116-T	2.5	Al (4X)
			02-17-89	112-T	2.5	Al
	R2DF (18516) + Test Blend No. 1 (A)	NT (‡)	03-28-89	119-T	2.5	Al
			03-29-89	120-T	2.5	Al
			03-30-89	121-T	2.5	304 SS
	R2DF (18516) +Test Blend No. 2 (A)	0.4	06-08-90	58-B	2.5	Al
			06-12-90	59-B	2.5	Al
			06-13-90	60-B	2.5	Al
			03-31-89	122-T	2.5	Al
			04-03-89	123-T	2.5	Al
	R2DF (18516) + Test Blend No. 3 (A)	NT	04-24-89	129-T	2.5	Al
			04-25-89	130-T	2.5	Al
	R2DF (18516) + Test Blend No. 4 (A)	1.2	06-21-90	247-T	2.5	Al
			06-19-90	246-T	2.5	Al
			05-29-89	142-T	2.5	Al
			05-03-89	133-T	2.5	Al
			05-04-89	134-T	2.5	Al
			05-22-89	139-T	2.5	304SS
			05-23-89	140-T	2.5	304SS
	R2DF (18516) + Test Blend No. 2 Aged at 80°C:					
	One Week	0.3	05-11-89	135-T	2.5	Al
	Two Weeks	0.3	05-16-89	137-T	2.5	Al
	R2DF (18516) + Test Blend No. 4 Aged at 80°C:					
	One Week	0.3	05-11-89	136-T	2.5	Al
18853	R2DF (18516) + 15% Light Cycle Oil	0.7	06-22-89	150-T	2.5	Al
			07-11-89	28-B	2.5	Al
			07-14-89	153-T	2.5	Al
	18853 + Test Blend No. 4	1.1	07-21-89	156-T	2.5	Al
			07-18-89	154-T	2.5	Al
	18853 + Test Blend No. 5 (A)	1.5	07-27-89	158-T	2.5	Al
			07-19-89	155-T	2.5	Al
18954	R2DF (18516) + 10% Light Coker Gas Oil	3.2	05-10-90	241-T	2.5	Al
			05-08-90	239-T	2.5	Al
			08-01-89	161-T	2.5	Al
			08-01-89	160-T	2.5	Al
			08-02-89	162-T	2.5	Al
			08-08-89	166-T	2.5	Al
18966	R2DF (18516) + 15% Light Coker Gas Oil	5.7	08-04-89	164-T	2.5	Al
			08-03-89	163-T	2.5	Al
			08-07-89	165-T	2.5	Al
			08-11-89	167-T	2.5	Al
19053	R2DF (18516) + 0.35% Marine Fuel Oil	0.3	06-06-90	57-B**	2.5	Al
			10-26-89	194-T**	2.5	Al
			10-31-89	195-T**	2.5	Al
19062	JP-8 (From Ft. Bliss)	0.1	11-08-89	198-T	2.5	Al
			11-28-89	204-T	2.5	Al
			12-07-89	207-T	2.5	Al

(A) Table 2
*REC = Recycle fuel.
†(4X) = Tube holder contains a volume 4 times more than standard tube holder.
‡NT = Not tested.
**Prefilter removed due to plugging problem with this blend.

Tubes Along With Standard ASTM D 3241 Ratings

Prefilter	Fuel Flow, mL/min	Temp, °C	Pressure Drop, mm of Hg	JFTOT Heater Tube Ratings: TDR Spun Rating at Station, mm	Visual Rating	Max. Thickness, DMD, cm × 10^{-7}, at Station, mm	Volume of Deposit, DMD, cc × 10^{-7}	Estimated Break Point Temp, Code 3, Temp, °C
Yes	3.0	232	0	3 at 40	2	68 at 24	185	250
No	3.0, REC*	232	125 in 34.5 min	13 at 36-42	3	<50	<50	
Yes	3.0	232	0	9 at 40	<3	<50	78	
Yes	3.0	245	0	5 at 44	2	<50	<50	
Yes	3.0	250	0	17 at 42	3	<50	<50	
Yes	3.0	260	125 in 117 min	18 at 40	4 Peacock	540 at 40	514	
No	3.0, REC	260	125 in 28.3 min	31 at 36	3 Peacock	200 at 38	286	
Yes	3.0	260	125 in 142.2 min	19 at 40	4 Peacock	488 at 38	652	
Yes	3.0	280	125 in 19.7 min	50+ at 38-48	>4 Peacock	1754 at 38	3030	
No	3.0	260	125 in 42.1 min	16 at 40	4 Peacock	348 at 42	457	260
No	3.0, REC	260	125 in 23.1 min	23 at 40	3 Peacock	497 at 40	710	
No	3.0	260	125 in 21.9 min	50+ at 48-54	>4 Peacock	1788 at 52	2412	
Yes	3.0	232	0	4 at 44	2	<50	<50	260
Yes	3.0	245	0	6 at 46	2	<50	<50	
Yes	3.0	260	5.0 in 150 min	10 at 42	3 Abnormal	71 at 22	95	
No	3.0	260	125 in 34.6 min	15 at 42	4 Peacock	511 at 42	713	
No	3.0, REC	260	125 in 25.5 min	13 at 32	4 Peacock	345 at 46	595	
No	3.0	260	125 in 34.4 min	18 at 46	4 Peacock	305 at 40	599	260
No	3.0, REC	260	125 in 32.8 min	23 at 40-46	4 Peacock	160 at 42	324	
Yes	3.0	230	0	11 at 42	3	<50	<50	230
Yes	3.0	240	125 in 137.2 min	17 at 46	4	<50	<50	
Yes	3.0	260	125 in 129.3 min	13 at 30	4 Abnormal	77 at 42	63	
No	3.0	260	125 in 22.9 min	50+ at 40-46	4 Peacock	1540 at 46	2675	
No	3.0, REC	260	125 in 19.3 min	50+ at 32-44	4 Peacock	2165 at 365	3683	
No	3.0	260	125 in 27.8 min	50+ at 50-54	4 Peacock	1034 at 52	1159	
No	3.0, REC	260	125 in 21.9 min	50+ at 48-58	4 Peacock	940 at 52	1129	
No	3.0	260	125 in 56.2 min	4 at 40-44	<3 Abnormal	68 at 48	161	
No	3.0	260	125 in 85.1 min	3 at 42	2	34 at 34	60	
No	3.0	260	125 in 35.2 min	2 at 38	2	45 at 44	52	
Yes	3.0	260	125 in 94.4 min	41 at 42	>4 Peacock	628 at 42	1184	
No	3.0	260	125 in 41.9 min	35 at 42	>4 Peacock	594 at 40	1077	
No	3.0, REC	260	125 in 36.1 min	16 at 30	4(A) Green	65 at 36	99	
No	3.0	232	125 in 28.6 min	14 at 30	>4 (A) Green	82 at 44	127	
No	3.0	260	125 in 10.9 min	50+ at 26-50	4 Peacock	2771 at 381	6364	
No	3.0	232	125 in 22.4 min	40 at 54	<4 Peacock	168 at 38	332	
No	3.0	260	125 in 7.1 min	50+ at 28-58	4 Peacock	2411 at 38	5030	
Yes	3.0	215	0	19 at 48	3	<50	<50	215
Yes	3.0	232	0	25 at 48	4 Peacock	174 at 42	303	
No	3.0	232	125 in 26.5 min	50+ at 45-55	4 Peacock	1154 at 46	1267	
Yes	3.0	260	125 in 8.3 min	50+ at 30-58	>4 Peacock	3088 at 34	5026	
No	3.0	260	125 in 8.6 min	50+ at 30-58	>4 Peacock	2851 at 34	4823	
No	3.0, REC	260	125 in 9.4 min	50+ at 32-58	>4 Peacock	1928 at 36	3712	
No	3.0	232	125 in 23.8 min	50+ at 46-56	>4 Peacock	994 at 48	1494	<232
Yes	3.0	260	125 in 9.2 min	50+ at 30-58	>4 Peacock	2940 at 34	4902	
No	3.0	260	125 in 7.7 min	50+ at 32-58	>4 Peacock	2805 at 36	5130	
No	3.0, REC	260	125 in 6.2 min	50+ at 30-58	>4 Peacock	1828 at 36	3885	
No	3.0	215	125 in 41.4 min	27 at 38	3	<50	<50	215
No	3.0	260	125 in 41.4 min	34 at 36-44	>4 Peacock	551 at 40	1141	
No	3.0, REC	260	125 in 72.2 min	35 at 42	>4 Peacock	468 at 38	1074	
Yes	3.0	260	0	0	1	<50	<50	>300
Yes	3.0	300	0	7 at 42-46	2	<50	<50	
No	3.0, REC	260	125 in 70.1 min	16 at 42	2	<50	<50	

TABLE C-5. Deposit Measuring Device (DMD) Evaluation of JFTOT

Base Fuel Code No.	Fuel Description	Total Insolubles, D2274-88, mg/100 mL	JFTOT Operating Conditions: Date	Test No.	Test Time, hr	Tube Metal
1325	3 Parts Burner Oil No. 2 + 1 Part Additive	0.3	04-06-90	44-B	2.5	Al
			04-17-90	51-B	2.5	Al
			04-05-90	43-B	2.5	Al
			03-30-90	40-B	2.5	Al
18987	Reference No. 2 Diesel Fuel R2DF	0.1	05-08-90	56-B	2.5	Al
			06-05-90	242-T	3.5	Al
			06-07-90	244-T	4.5	Al
			06-06-90	243-T	5.5	Al
			06-22-90	248-T	2.5	Al
			06-13-90	245-T	2.5	Al
			11-05-90	1781-J	7.5*	Al
19393	JP-8	0.1	07-18-90	249-T	2.5	Al
			07-20-90	250-T	2.5	Al
			07-24-90	66-B	2.5	Al
			11-06-90	1782-J	7.5*	Al
15542	1% Sulfur, w/o Additives	2.1	08-03-90	256-T	2.5	Al
			07-20-90	64-B	2.5	Al
			07-24-90	252-T	2.5	Al
			08-30-90	259-T	2.5	Al
			08-31-90	260-T	2.5	Al
			09-18-90	263-T	2.5	Al
			09-20-90	264-T	2.5	Al
			09-24-90	266-T	2.5	Al
			09-25-90	267-T	2.5	Al(4X)‡
19444	1% Sulfur, w/o Additives	2.0	07-31-90	255-T	2.5	Al
			07-26-90	254-T	2.5	Al
			07-25-90	253-T	2.5	Al
			09-04-90	261-T	2.5	Al
(Different Drum of 15542)			09-05-90	262-T	2.5	Al
			09-21-90	265-T	2.5	Al
			09-27-90	268-T	2.5	Al (4X)
			10-01-90	269-T	3.75	Al
			10-05-90	270-T	7.5	Al
			11-02-90	1780-J	7.5*	Al

*Three each 2.5-hour runs, aerating as per procedure, single tube.
†REC = Recycle fuel.
‡(4X) = Tube holder contains a volume 4 times more than standard tube holder.

Tubes Along With Standard ASTM D 3241 Ratings (Cont'd)

				JFTOT Heater Tube Ratings				
Prefilter	Fuel Flow, mL/min	Temp, °C	Pressure Drop, mm of Hg	TDR Spun Rating at Station, mm	Visual Rating	Max. Thickness, DMD, cm × 10^{-7}, at Station, mm	Volume of Deposit, DMD, cc × 10^{-7}	Estimated Break Point Temp, Code 3, Temp, °C
Yes	3.0	200	0	0	1	<50	<50	215
Yes	3.0	215	0	17 at 44	3	<50	<50	
Yes	3.0	232	0	19 at 32	>4	<50	51	
Yes	3.0	260	0	37 at 44	4 Peacock	654 at 40	1407	
Yes	3.0	260	0	4 at 40	1	<50	<50	260
Yes	3.0	260	0	11 at 44	2	<50	<50	
Yes	3.0	260	0	20 at 30	2	<50	<50	
Yes	3.0	260	0	24 at 44	3	<50	<50	
Yes	3.0	270	10 in 149.5 min	16 at 36	3 Peacock	85 at 38	92	
Yes	3.0	280	125 in 72.1 min	21 at 44	4 Peacock	388 at 42	506	
Yes	3.0	260	0	23 at 44	4	<50	<50	
Yes	3.0	260	0	0	1	<50	<50	300
Yes	3.0	280	0	0	2	<50	<50	
Yes	3.0	300	0	30 at 48	3	<50	<50	
Yes	3.0	260	0	13 at 50	1	<50	<50	
Yes	3.0	250	0	10 at 44	3	<50	<50	250
Yes	3.0	260	0	26 at 36-42	<4	<50	<50	
Yes	3.0	260	0	27 at 40-45	<4	<50	<50	
Yes	2.0	232	0	6 at 34	2	<50	<50	
Yes	1.0	232	0	5 at 34	2	<50	<50	
Yes	2.0	260	0	18 at 44	<4	<50	<50	
Yes	1.0	260	104.9 in 150 min	21 at 42	4	<50	<50	
No	3.0, REC†	260	125 in 48.3 min	21 at 42-46	4	<50	<50	
Yes	3.0	260	9.5 in 150 min	16 at 40-44	3	<50	<50	
Yes	3.0	215	0	10 at 42	3	<50	<50	215
Yes	3.0	232	0	30 at 50	>4	<50	<50	
Yes	3.0	260	125 in 70.6 min	50+ at 34-58	>4 Peacock	1091 at 42	1769	
Yes	2.0	232	0	15 at 40	3	<50	<50	
Yes	1.0	232	0	18 at 38	<4	<50	<50	
Yes	1.0	260	125 in 112.3 min	17 at 48	>4 Abnormal	<50	<50	
Yes	3.0	260	69 in 150 min	18 at 52	>4 Peacock	<50	<50	
Yes	2.0	260	125 in 171.2 min	29 at 42	>4 Peacock	228 at 38	334	
Yes	1.0	260	125 in 118.1 min	44 at 38	4 Peacock	274 at 40	455	
Yes	3.0	260	2 in 150 min	37 at 43	4 Peacock	280 at 42	597	

TABLE C-6. Results of 150°C Accelerated Stability Test of Fuel Before IFBT Run and After IFBT Run
(For IFBT Nos. 18 through 29)

	Before IFBT				After IFBT				
	150°C Test Total Insolubles		150°C Test D 1500 Color			150°C Test Total Insolubles		150°C Test D 1500 Color	
Fuel Description	1.5 Hr mg/100 mL	3.0 Hr mg/100 mL	1.5 Hr Color	3.0 Hr Color	IFB Test*	1.5 Hr mg/100 mL	3.0 Hr mg/100 mL	1.5 Hr Color	3.0 Hr Color
AL-18516-F					18-B	7.5	11.6	5.0	7.0
Ref. No. 2	0.6	0.6	1.5	1.5	18-D	9.7	13.3	6.0	8.0
					19-B	5.4	6.3	4.5	6.0
					19-D	9.5	13.4	7.0	7.5
AL-18516-TB2									
Ref. No. 2 + Test	0.5	0.7	1.0	1.0	20-B	11.5	17.9	8.0	8.0
Blend No. 2					20-D	13.4	13.5	6.5	7.5
AL-18516-TB4									
Ref. No. 2 + Test	2.1	5.3	1.5	2.0	21-B	7.9	13.9	4.0	7.5
Blend No. 4					21-D	15.3	17.1	7.5	8.0
AL-18954-F									
Ref. No. 2 + 10%	5.1	7.5	>8	>8	22-B	NES†	NES	NES	NES
Light Coker Gas					22-D	NES	NES	NES	NES
Oil									
AL-19053-F									
Ref. No. 2 + 0.35%	3.1	9.5	>8	>8	23-B	4.5	12.3	>8.0	>8.0
Marine Fuel Oil					23-D	13.7	19.5	>8.0	>8.0
AL-19062-F	0.6	2.1	0.5	1.0	24-B	1.0	2.4	1.0	1.5
JP-8					24-D	0.7	3.1	1.0	2.5
FL-1325-F									
3 Part Burner Oil #2	2.4	4.9	6.0	7.0	25-B	5.1	8.1	7.0	7.5
+ 1 Part Additive					25-D	7.7	14.3	7.0	8.0
AL-18987-F	0.4	0.5	1.0	1.0	26-B	0.2	0.4	1.0	1.0
Ref. No. 2					26-D	6.1	10.7	3.5	5.5
AL-19393-F	0.1	0.1	0.5	0.5	27-B	0.1	0.2	0.5	0.5
JP-8					27-D	0.1	0.3	0.5	0.5
AL-15542-F									
1% Sulfur without	3.7	6.1	1.5	6.5	28-B	3.3	4.3	5.0	7.5
Additives					28-D	2.1	3.1	5.5	7.0
AL-19444-F									
1% Sulfur without	4.8	6.1	7.5	7.5	29-B	5.5	7.5	7.5	8.0
Additives					29-D	2.5	3.9	6.0	7.5

* B = Bosch Injector, D = Detroit Diesel Injector.
† NES = Not enough sample.

DISTRIBUTION LIST

Department of Defense

DEFENSE TECHNICAL INFORMATION CTR
CAMERON STATION 12
ALEXANDRIA VA 22314

DEPT OF DEFENSE
OASD/P&L
ATTN: L/EP (MR DYCKMAN) 1
WASHINGTON DC 20301-8000

DEPT OF DEFENSE
OASD/R&E
ATTN: DUSDRE (RAT) (DR DIX) 1
WASHINGTON DC 20301-8000

DEFENSE ADVANCED RES PROJECTS AGY
DEFENSE SCIENCES OFFICE 1
1400 WILSON BLVD
ARLINGTON VA 22209

CDR
DEFENSE FUEL SPLY CTR
ATTN: DFSC-Q (MR MARTIN) 1
CAMERON STATION
ALEXANDRIA VA 22304-6160

DEFENSE STNDZ OFFICE
ATTN: DR S MILLER 1
5203 LEESBURG PIKE, SUITE 1403
FALLS CHURCH VA 22041

CDR
DEFENSE LOGISTICS AGY
ATTN: DLA-SE 1
CAMERON STATION
ALEXANDRIA VA 22304-6179

Department of the Army

CDR
US ARMY BELVOIR RESEARCH,
DEVELOPMENT AND ENGINEERING CTR
ATTN: SATBE-F 1
SATBE-FL 10
SATBE-BT 2
SATBE-TQ 1
SATBE-FG 1
AMSTR-ABCE (MR COOK) 1
FORT BELVOIR VA 22060-5606

HQ, DEPT OF ARMY
ATTN: DALO-TSE (COL HOLLEY) 1
DALO-TSZ-B (MR KOWALCZYK) 1
SARD-TR 1
SARD-TC 1
WASHINGTON DC 20310-0561

DIRECTOR
US ARMY MATERIEL SYSTEMS ANALYSIS ACTIVITY
ATTN: AMXSY-CM (MR NIEMEYER) 1
AMXSY-CR 1
ABERDEEN PROVING GROUND MD
21005-5006

DIRECTOR
AVIATION APPLIED TECH DIR
ATTN: AMSAT-R-T (MR MORROW) 1
FORT EUSTIS VA 23604-5577

CDR
US ARMY MATERIEL COMMAND
ATTN: AMCRD-S 1
AMCOB (MR ASHLEY) 1
5001 EISENHOWER AVE
ALEXANDRIA VA 22333-0001

CDR
US ARMY TANK-AUTOMOTIVE COMMAND
ATTN: AMSTA-RG (DR McCLELLAND) 1
AMSTA-RGP (MR HNATCZUK) 1
AMSTA-RGR (DR BRYZIK) 1
AMSTA-MTC (MR GAGLIO) 1
AMSTA-MC (MR GLADIEUX) 1
AMSTA-RS (DR PARKS) 1
WARREN MI 48397-5000

CDR
THEATER ARMY MATERIAL MGMT
CENTER (200TH)-DPGM
DIRECTORATE FOR PETROL MGMT
ATTN: AEAGD-MMC-PT-Q 1
APO NY 09052

DOD PROJ MGR, MOBILE ELECTRIC POWER
US ARMY TROOP SUPPORT COMMAND
ATTN: AMCPM-MEP-TM 1
7500 BACKLICK ROAD
SPRINGFIELD VA 22150

CDR
US ARMY PETROLEUM CENTER
ATTN: STRGP-F 1
STRGP-FT 1
STRGP-FE, BLDG 85-3
(MR GARY SMITH) 1
NEW CUMBERLAND PA 17070-5008

CDR
US ARMY LABORATORY COMMAND
ATTN: AMSLC-TP-PB 1
ADELPHI MD 20783-1145

CDR
US ARMY NATICK RD&E CTR
ATTN: SATNC-UE 1
NATICK MA 01760-5020

CDR
US ARMY YUMA PROVING GROUND
ATTN: STEYP-MT-TL-M 1
YUMA AZ 85364-9103

CDR
US ARMY TANK-AUTOMOTIVE CMD
PROGM EXEC OFF, CLOSE COMBAT
APEO SYSTEMS, ATTN: AMCPEO-CCV-S 1
PM ABRAMS, ATTN: AMCPM-ABMS 1
PM BFVS, ATTN: AMCPM-BFVS 1
PM 113 FOV, ATTN: AMCPM-M113 1
PM M9 ACE, ATTN: AMCPM-MA 1
PM IMP REC VEH, ATTN: AMCPM-IRV 1
WARREN MI 48397-5000

CDR
US ARMY RESEARCH OFFICE
ATTN: SLCRO-EG (DR MANN) 1
SLCRO-CB 1
RSCH TRIANGLE PARK NC 27709-2211

CDR
US ARMY FOREIGN SCIENCE & TECH CTR
ATTN: AIAST-RA-ST3 (MR BUSI) 1
FEDERAL BLDG
CHARLOTTESVILLE VA 22901

CDR
US ARMY LEA
ATTN: LOEA-PL (MR LeVAN) 1
NEW CUMBERLAND ARMY DEPOT
NEW CUMBERLAND PA 17070

CDR
US ARMY TANK-AUTOMOTIVE CMD
PROGM EXEC OFF, COMBAT SUPPORT
PM LIGHT TACTICAL VEHICLES,
ATTN: AMCPM-TVL 1
PM MEDIUM TACTICAL VEHICLES,
ATTN: AMCPM-TVM 1
PM HEAVY TACTICAL VEHICLES,
ATTN: AMCPM-TVH 1
WARREN MI 48397-5000

PETROLEUM FIELD OFFICE WEST,
MR. ECCLESTON 1
DDRW, BLDG 247, TRACEY LOCATION
P O BOX 96001
STOCKTON CA 95296-0960

CDR
US ARMY ORDNANCE CENTER & SCHOOL
ATTN: ATSL-CD-CS 1
ABERDEEN PROVING GROUND MD
21005-5006

CDR
US ARMY ENGINEER SCHOOL
ATTN: ATSE-CD 1
FORT LEONARD WOOD MO 65473-5000

HQ, US ARMY T&E COMMAND
ATTN: AMSTE-CM-R-O 1
AMSTE-TE-T 1
ABERDEEN PROVING GROUND MD
21005-5006

CDR
CONSTRUCTION ENG RSCH LAB
ATTN: CECER-EN 1
P O BOX 4005
CHAMPAIGN IL 61820

HQ, US ARMY ARMOR CENTER
ATTN: ATSB-CD-ML 1
ATSB-TSM-T 1
FORT KNOX KY 40121

CDR
US ARMY EUROPE & SEVENTH ARMY
ATTN: AEAGD-TE 1
APO NEW YORK 09403

CDR
US ARMY QUARTERMASTER SCHOOL
ATTN: ATSM-CDM 1
ATSM-PWD 1
FORT LEE VA 23801

PROJECT MANAGER
PETROLEUM & WATER LOGISTICS
ATTN: AMCPM-PWL 1
4300 GOODFELLOW BLVD
ST LOUIS MO 63120-1798

CDR
COMBINED ARMS COMBAT DEV ACTY
ATTN: ATZL-CAT-E 1
ATZL-CAT-A 1
FORT LEAVENWORTH KS 66027-5300

HQ
US ARMY TRAINING & DOCTRINE CMD
ATTN: ATCD-SL-5 1
FORT MONROE VA 23651-5000

CDR
US ARMY TRANSPORTATION SCHOOL
ATTN: ATSP-CD-MS 1
FORT EUSTIS VA 23604-5000

CDR
101ST AIRBORNE DIV (AASLT)
ATTN: AFZB-KE-J 1
AFSB-KE-DMMC 1
FORT CAMPBELL KY 42223

CDR
US ARMY FIELD ARTILLERY SCHOOL
ATTN: ATSF-CD 1
FORT SILL OK 73503-5600

CDR
US ARMY INFANTRY SCHOOL
ATTN: ATSH-CD-MS-M 1
FORT BENNING GA 31905-5400

HQ, 172D INFANTRY BDE (ALASKA)
ATTN: AFZT-DI-L 1
DIR OF IND OPER
FORT RICHARDSON AK 99505

CDR
US ARMY COMBINED ARMS & SUPPT CMD AND FT LEE
ATTN: ATCL-CD 1
ATCL-MS 1
FORT LEE VA 23801-6000

CDR
US ARMY TANK-AUTOMOTIVE CMD
PROD MGR
CCE/SMHE
ATTN: AMCPM-TVC 1
WARREN MI 48397-5000

HQ, EUROPEAN CMD
ATTN: J4/7-LJPO 1
VAIHINGEN, GE
APO NEW YORK 09128

Department of the Navy

CDR
NAVAL AIR PROPULSION CENTER
ATTN: PE-33 (MR D'ORAZIO) 1
P O BOX 7176
TRENTON NJ 06828-0176

CDR
DAVID TAYLOR RESEARCH CENTER
ATTN: CODE 2832 (MS BIEDERICH) 1
CODE 2759 (MR STRUCKO) 1
ANNAPOLIS MD 21402-5067

CDR
NAVAL SEA SYSTEMS COMMAND
ATTN: CODE 05M32 (MR DEMPSEY) 1
WASHINGTON DC 20362-5101

PROJ MGR, M60 TANK DEVELOPMENT
ATTN: USMC-LNO 1
US ARMY TANK-AUTOMOTIVE COMMAND (TACOM)
WARREN MI 48397-5000

CDR
NAVAL PETROLEUM OFFICE
ATTN: CODE 40 (MR LONG) 1
CAMERON STATION
ALEXANDRIA VA 22304-6180

DEPARTMENT OF THE NAVY
HQ, US MARINE CORPS
ATTN: LLP-2 1
WASHINGTON DC 20380

CDR
NAVAL AIR SYSTEMS COMMAND
ATTN: CODE 53632F (MR MEARNS) 1
WASHINGTON DC 20361-5360

CDR
NAVAL RESEARCH LABORATORY
ATTN: CODE 6180 1
WASHINGTON DC 20375-5000

CG
USMC RD&A CMD
ATTN: CODE SSCMT 1
WASHINGTON DC 20380-0001

DEPUTY CG
USMC RD&A COMMAND
ATTN: PM GND WEAPONS (CB6T) 1
QUANTICO VA 22134-5080

CG
FLEET MARINE FORCE PACIFIC
ATTN: G4 1
CAMP H M SMITH HI 96861

CG
FLEET MARINE FORCE ATLANTIC
ATTN: G4 1
NORFOLK VA 23511

OFFICE OF CHIEF OF NAVAL RESEARCH
ATTN: OCNR-126 (DR ROBERTS) 1
ARLINGTON VA 22217-5000

Department of the Air Force

HQ AIR FORCE SYSTEMS COMMAND
ATTN: AFSC/LGTV 1
ANDREWS AFB MD 20334

CDR
US AIR FORCE WRIGHT AERO LAB
ATTN: POSF (MR DELANEY) 1
WRIGHT-PATTERSON AFB OH 45433-6563

CDR
SAN ANTONIO AIR LOGISTICS CTR
ATTN: SAALC/SFT (MR MAKRIS) 1
SAALC/LDPE (MR ELLIOT) 1
KELLY AIR FORCE BASE TX 78241

CDR
WARNER ROBINS AIR LOGISTIC CTR
ATTN: WRALC/LVR-1 (MR PERAZZOLA) 1
ROBINS AFB GA 31098

HQ US AIR FORCE
ATTN: LEYSF 1
WASHINGTON DC 20330

CDR
USAF 3902 TRANSP SQDRN
ATTN: LGTVP (MR VAUGHN) 1
OFFUTT AFB NE 68113

CDR
DET 29
ATTN: SA-ALC/SFM 1
CAMERON STATION
ALEXANDRIA VA 22304-6179

Other Organizations

US DEPARTMENT OF ENERGY
ATTN: MR JOHN RUSSELL 1
MAIL CODE CE-151
FORRESTAL BLDG
1000 INDEPENDENCE AVE. SW
WASHINGTON DC 20585

ENVIRONMENTAL PROTECTION AGY
AIR POLLUTION CONTROL 1
2565 PLYMOUTH ROAD
ANN ARBOR MI 48105